Evaluation of different AI applications for operational logistic systems

Evaluation unterschiedlicher KI-Anwendungen für operative Logistiksysteme

Scientific work to obtain the Master's Degree
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Abstract

The integration of artificial intelligence (AI) technology in the logistics industry has become a growing trend as it offers potential benefits to optimize operations, improve efficiency and, overall, transform the industry. However, a lack of consensus on how to objectively evaluate the performance of AI-driven logistics systems poses significant challenges for organizations seeking to leverage AI.

Following a search for information supported by a bibliometric analysis to contextualize the thesis objectives and develop theoretical frameworks of AI and operational logistics separately, the study proceeds to study the intersection of the two fields.

This thesis aims to develop a comprehensive framework for evaluating the performance of AI systems in operational logistics. The primary motivation for this study is to address the need for an objective evaluation system that companies can use to measure the effectiveness of their AI-driven logistics systems. By answering critical questions such as how to track, measure and examine the performance of AI systems in logistics operations, and analyse the final results of the evaluation, this study can help organizations gain a better understanding of the impact of AI on their logistics operations. The research seeks to contribute to the growing body of knowledge on the implementation and evaluation of AI technologies in logistics.

The outcome, which is the general evaluation system developed in this study, enables a company to customize it according to its requirements and goals, and apply it to its particular AI applications. The standardized evaluation system provided in the thesis can help organizations make data-driven decisions on the implementation and/or improvement of AI applications and optimize their logistics operations, leading to improved efficiency, reduced costs, and increased customer satisfaction.

Keywords

artificial intelligence, machine learning, operational logistics, internal logistics, AI applications, logistics management, evaluation, key performance indicators, evaluation criteria

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Last but not least, I would like to acknowledge my family, the most important pillar in my life, for their constant love and encouragement throughout my whole life. Their kindness, affection, understanding and belief in my abilities have always been the fuel and the reason for my achievements and for being the person I am today. I cannot express in words how grateful I am and how much I love them.

Thank you all from the bottom of my heart for your contribution towards this thesis and career and for being a part of my life's journey.

Foreword

The present work was created under the scientific and content-related guidance of **Philipp Wuddi**, a research assistant at the Chair for Materials Handling, Material Flow, Logistics (fml) at the Technical University of Munich.

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Munich, 28.04.2023

Location, Date

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List of Abbreviations

Abbreviation	Meaning
AI	Artificial Intelligence
ML	Machine Learning
WoS	Web of Science
AGV	Automated Guided Vehicles
RFID	Radio Frequency Identification
LIS	Logistics Information System
DT	Digital Twin
1PL, 2PL, etc.	First-Party Logistics, Second-Party Logistics, etc.
PI	Physical Internet
AMR	Autonomous Mobile Robot
AS/RS	Automatic Storage and Retrieval Systems
WCS	Warehouse Control System
WMS	Warehouse Management System
NLP	Natural Language Processing
RPA	Robotic Process Automation
ROI	Return on Investment
KPI	Key Performance Indicator

List of Symbols

Symbol	Unit	Meaning
S_{max}	[-]	Score of the KPI_{act} value to be maximized
S_{min}	[-]	Score of the KPI_{act} value to be minimized
$S_{max,baseline}$	[-]	Baseline score of the KPI_{act} value to be maximized
$S_{min,baseline}$	[-]	Baseline score of the KPI_{act} value to be minimized
KPI_{act}	[-]	Actual KPI value to be normalized
KPI_{min}	[-]	Value below which KPI_{act} would score 0 (maximizing) or 10 (minimizing)
KPI_{max}	[-]	Value above which KPI_{act} would score 10 (maximizing) or 0 (minimizing)
$(Abs.WF)_{ij}$	[-]	Absolute weighting factor for KPI j from criterion i
$(Final\ Rel.WF)_{ij}$	[-]	Final relative WF for KPI j from criterion i
$(Rel.WF)_{ij}$	[-]	Relative WF (uncorrected) for KPI j from criterion i
WF_i	[-]	Total WF for criterion i
N_i	[-]	Number of KPIs under criterion i

1 Introduction

1.1 Motivation

The integration of AI technology in operational and internal logistics fields has significant potential to transform the industry. However, the challenge lies in assessing the performance of these systems objectively. Despite the numerous benefits of AI, there is a lack of consensus on how to evaluate its impact on logistics operations accurately. Furthermore, the lack of a standardized evaluation system can hinder organizations' ability to compare their AI-driven logistics systems' effectiveness against their peers, leading to a lack of understanding of their return on investment.

Therefore, the primary motivation for this study is to provide a comprehensive framework for evaluating the performance of AI systems in operational logistics. This framework aims to address the need for an objective evaluation system that companies can use to measure the effectiveness of their AI-driven logistics systems. By answering critical questions such as how to track, measure, and examine the performance of AI systems in logistics operations, this study can help organizations to gain a better understanding of the impact of AI on their logistics operations.

Overall, the research seeks to contribute to the growing body of knowledge on the implementation and evaluation of AI technologies in logistics. By providing a standardized evaluation system, this study can help organizations to make data-driven decisions and optimize their logistics operations, leading to improved efficiency, reduced costs, and increased customer satisfaction.

1.2 Problem statement

The logistics industry is witnessing a growing trend of integrating AI technology to optimize operations and improve efficiency. However, despite the numerous benefits of AI-driven logistics systems, there is a lack of consensus on how to evaluate their performance objectively, which poses a significant challenge for organizations seeking to leverage AI in their logistics operations.

The primary objective of this research is to develop a comprehensive framework for evaluating the performance of AI systems in logistics operations. The framework will address critical questions such as how to track, measure, and examine the performance of AI systems in logistics operations accurately.

There is a need to develop a standardized evaluation system for AI-driven logistics systems, which is critical for organizations seeking to gain a competitive advantage in the market. This system will help organizations to make data-driven decisions and optimize their logistics operations, leading to improved efficiency, reduced costs, and increased customer satisfaction.

The lack of a standardized evaluation system arises due to several factors, including the lack of a consensus on evaluation metrics, limited understanding of AI's impact on logistics operations, and difficulty in tracking and measuring performance. These factors make it challenging for organizations to assess the effectiveness of their AI-driven logistics systems accurately.

To address this problem, the framework aims to identify KPIs for evaluating the effectiveness of AI-driven logistics systems. The framework will also develop a methodology for tracking and measuring the performance of AI systems in logistics operations. The analysis of the impact of AI on logistics operations will identify areas for improvement. Insights into how organizations can effectively implement and evaluate AI technologies in their logistics operations will be provided.

By achieving these objectives, the framework will provide organizations with a standardized and objective evaluation system for measuring the effectiveness of their AI-driven logistics systems. This system will help organizations to optimize their logistics operations, improve efficiency, reduce costs, and gain a competitive advantage in the market.

1.3 Research questions

The research aims to answer these questions:

1. What is the current general situation of AI in logistics?
2. How can a company evaluate the performance of its various AI applications in operational logistics?
3. How can the company analyze and interpret this evaluation to achieve continuous improvement of its AI-driven systems?

2 Methodology

2.1 Research methodology

Bibliometric analysis is a well-established research methodology used to explore a specific research topic through the analysis of published literature. In this study, bibliometric analysis was employed as a research methodology to investigate the research landscape related to the application of AI in logistics. The most relevant documents were extracted from the Web of Science (WoS) database using specific inclusion and exclusion criteria. WoS is widely recognized as a reliable academic database for bibliometric research as it contains a large number of high-profile and high-quality international academic publications, it offers robust metadata suitable for bibliometric analyses and it covers a longer period than alternative databases with equivalent domain coverage such as Scopus or Google Scholar. All document types available in the WoS Core Collection were used for the analysis [Baw-2020]. The search consisted of using a combination of the keywords "artificial intelligence", "logistic*", and "supply chain*" [Web-2023] and looking for publications that contained these in any of their fields (title, abstract, author keywords, source title, etc.). These keywords were selected to capture a comprehensive sample of publications related to the intersection of AI and logistics. A total of 375 publications were identified that satisfied the search criteria.

Keyword analysis

The identified publications were subsequently processed using VOSviewer, a software tool commonly used in bibliometric analysis to generate network visualizations and identify patterns in the data. Through the use of VOSviewer, a network diagram was generated in Figure 2-1, which visualizes the relationships between the publications based on the co-occurrence of keywords to judge the relatedness of the words. The generated network structure provides visual representations of the relationships between the publications in the sample, allowing for the identification of clusters of related publications based on specific themes or topics. A review of the keywords for author keywords, including those that appear at least 5 times throughout the database, was performed. To guarantee data reliability, the study relied on a manual selection, which resulted in 30 (meeting the threshold of at least 5 occurrences) out of a total of 1120 identified author keywords being deemed suitable for the study. The keywords that, in isolation, did not explain anything were filtered out. [DiV-2021]

The text mining routine produces a map where the terms’ distance between each other represents a connection between different keywords. The word size depends on its number of occurrences in the 375 selected articles and each keyword is given a color depending on the topic cluster that has been assigned to it.

Through the analysis of the content of these clusters, key research areas, trends, and gaps in the literature were identified. As Figure 2-1 shows, “artificial intelligence”, “supply chain” or “supply chain management”, and “logistics,” which are at the core of the map, were the study’s keywords. In fact, these keywords have been used as a constant throughout the research period of data collection. These keywords indicate the growing interest in the use of advanced technologies to optimize supply chain processes and increase efficiency. [DiV-2021]

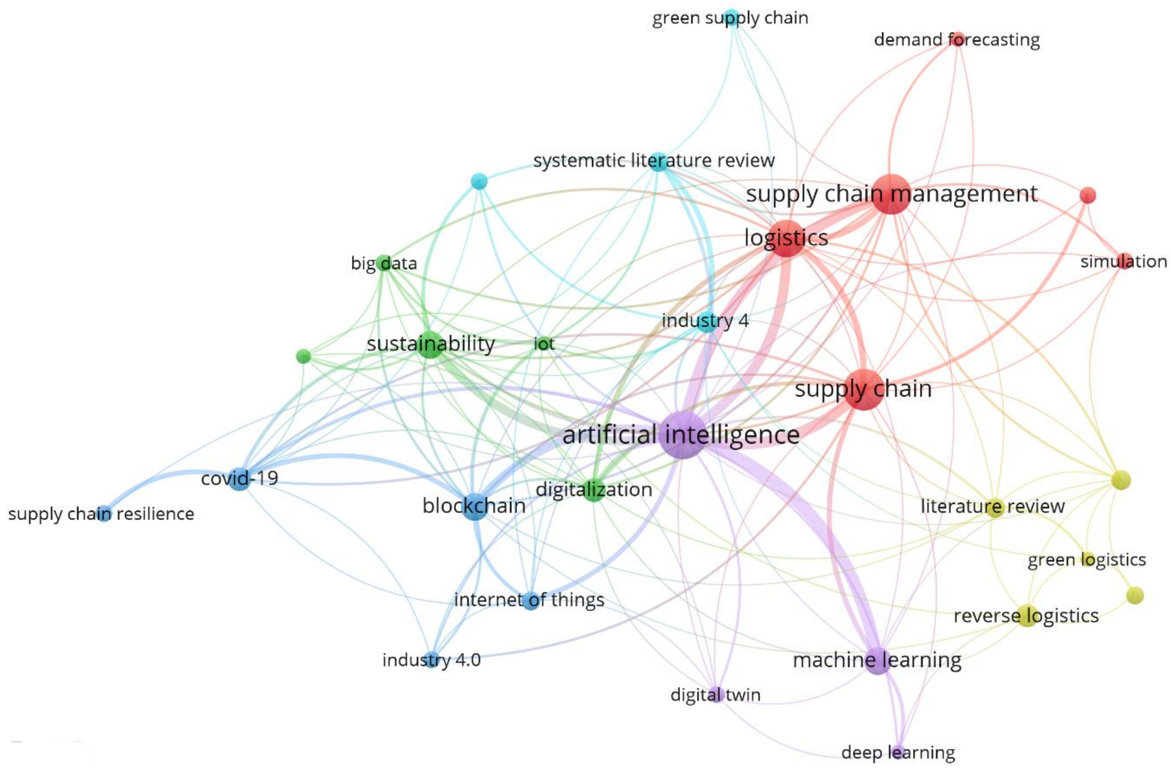

Figure 2-1: Network visualization map of the author keywords

The map in Figure 2-1 shows clusters of related keywords, which give us an overview of the most prominent topics and trends in the field.

The foremost cluster (red), consisting of 40+ occurrences, is primarily focused on supply chain management, logistics, demand forecasting, etc. This cluster emphasizes the importance of optimizing the supply chain, given its complexity, which can be significantly improved with the application of AI. The magnitude of research in this area underscores the critical role of AI in logistics.

The purple cluster is centered on the most essential keyword in AI logistics: artificial intelligence (containing 57 occurrences). This cluster demonstrates the growing significance of AI technologies and their potential to transform the logistics industry. Keywords like machine learning, deep learning with over 20 occurrences and other like digital twin also belong to this cluster. These techniques offer a means to optimize logistics operations, reduce costs, and increase efficiency. The research studying various AI technologies aimed at enhancing logistics operations, reveals a substantial body of work in this field.

The blue cluster is primarily concerned with the role of blockchain technology in logistics with 17 occurrences. The incorporation of blockchain technology can improve supply chain operations' transparency and security, making it an increasingly important tool for logistics companies. It is clustered with "covid-19" and "industry 4.0". This suggests that blockchain technology is being explored for its potential to improve logistics and supply chain management, especially in light of the COVID-19 pandemic. With over 13 occurrences, the cluster is also devoted to the "industry 4.0" and "internet of things". These topics are closely related and indicate the growing interest in the application of IoT and Industry 4.0 technologies in logistics and supply chain management.

The "sustainability" cluster (green) has a weight of 17 and is related to "green logistics" and "green supply chain". This cluster indicates the increasing importance of sustainability in logistics and supply chain management, as businesses aim to reduce their environmental footprint and embrace sustainable practices.

In summary, the bibliometric map of prominent publications related to AI in operational logistics indicates that this field is evolving rapidly and expanding. AI is gaining increasing importance in the logistics industry, and research is exploring its potential for enhancing supply chain management and logistics operations. Themes such as AI technologies and applications, optimization, sustainability, and transparency are essential in this field, underscoring the need for environmentally friendly and more efficient logistics operations. Overall, this keyword analysis highlights the relevance of AI in logistics as a crucial area of study that will continue to be indispensable as the industry continues to innovate and evolve. These insights can guide future research and development in the field, as businesses seek to leverage AI and other emerging technologies to improve their logistics and supply chain management practices.

Further analyses

In addition to the keyword analysis, WoS and VOSviewer allow more types of analysis of the 375 publications obtained in the search, which may be interesting to understand the importance of the topic, trends in recent years, most relevant publications in terms of number of citations, the most prolific authors and sources/institutions on the matter, etc. Some of them will be presented below.

From the WoS itself, the number of publications per year can be extracted from the search. Figure 2-2 illustrates the evolution of publications on AI in logistics/supply chains from 1996 to 2022, during which period there has been a slow increase over the past two decades, but the growth has been particularly rapid in recent years. Before 2010, there were only a few publications per year on these topics. However, in the last few years, the number of publications has increased considerably. For example, in 2018, there were 7 publications on these topics, and in 2022, there were 91, which is a large increase compared to previous years. The rise of AI in recent years is likely one of the main drivers behind the increased interest in these topics. The increasing number of publications on AI, logistics, and supply chain topics indicates the growing relevance of these topics in the business world, and it suggests that there is a strong interest in exploring the potential benefits of using AI in logistics and supply chain management. AI has the potential to revolutionize logistics and supply chains, and this has significant implications for businesses looking to streamline their operations and increase efficiency.

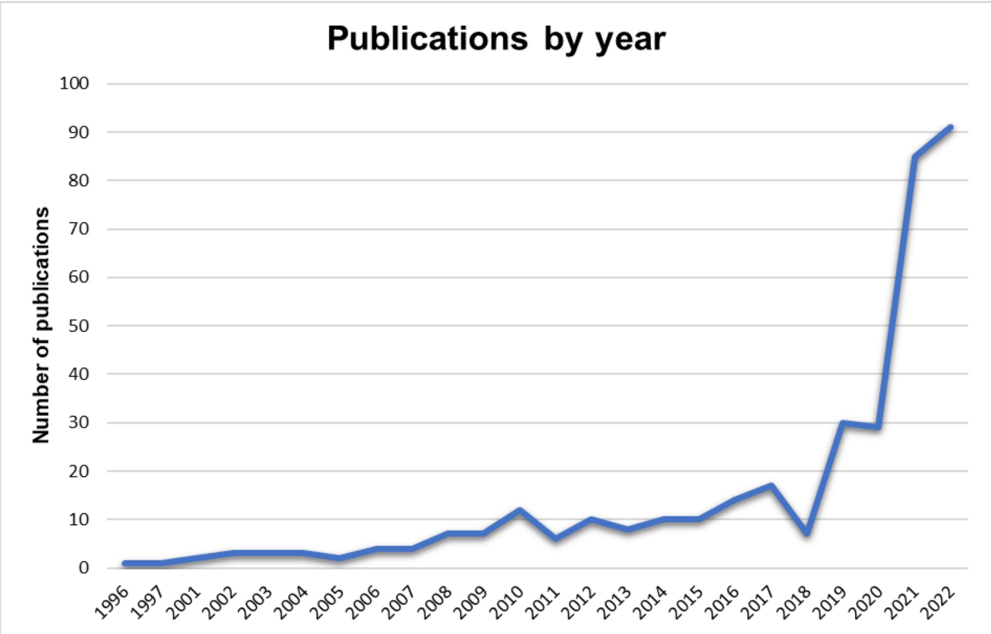

Figure 2-2: Number of publications by year

By importing the data from the 375 WoS search publications into VOSviewer, an analysis of the most important sources on the subject can be performed. Table 2-1 lists the most successful and key journals that have published papers on AI, supply chains and logistics, along with the number of documents and citations they have received. The sources include journals and publications related to production management systems, artificial intelligence, sustainability, logistics, transportation, and operations research. Some of the notable sources in the list include the “International Journal of Production Research” with 321 citations, “Engineering Applications of Artificial Intelligence” with 244 citations, and “Sustainability” with 71 citations. The latter (with 11 documents), along with “Advances in Production Systems” (with 17 documents), “Engineering Applications of Artificial Intelligence” and “International Journal of Logistics Management” (both with 8 documents each) are the titles of the sources that have the most publications among the 375 selected in the search.

Source titles	**# of documents**	**# of citations**
Advances in Production Management Systems: Artificial Intelligence for Sustainable and Resilient Production Systems	17	10
Sustainability	11	71
Engineering Applications of Artificial Intelligence	8	244
International Journal of Logistics Management	8	125
International Journal of Logistics-Research and Applications	7	189
International Journal of Production Research	7	321
Journal of Cleaner Production	7	77
Transportation Research Part e-Logistics and Transportation Review	7	40
Computers & Industrial Engineering	6	136
Annals of Operations Research	5	101

Table 2-1: Most active source titles

In the forthcoming analysis, a table comprising an in-depth evaluation of the most notable authors will be presented. Out of the 375 publications identified through the search, a total of 1161 authors were found to have contributed. Employing VOSviewer to filter for authors with a minimum of three publications, 23 authors were selected and are presented in the ensuing table. Table 2-2 shows the productivity and citation counts of authors in a particular topic area. Based on this data, we can identify the most productive authors as those who have published the highest number of documents on the topic. Matthias Klumpp and Shivam Gupta are tied for the most productive authors, with six documents each. However, productivity alone may not be the best indicator of impact. Therefore, we can also look at the number of citations each author has received for their work on the topic. Here, we see that Arpan Kumar Kar has an exceptionally high number of citations (546), indicating that his work has had a significant impact on the field. Other highly cited authors include C.K.M. Lee, Yaser Rahimi and Matthias Klumpp.

Authors	Documents	Citations
Klumpp, Matthias	6	126
Gupta, Shivam	6	80
Abraham, Ajith	5	46
Gunasekaran, Angappa	5	95
Goodarzian, Fariba	4	45
Kawa, Arkadiusz	4	15
Kumar, Ajay	4	54
Luthra, Sunil	4	44
Wiktorsson, Magnus	4	3
Gong, Yeming	3	3
Grzybowska, Katarzyna	3	23
Kar, Arpan Kumar	3	546
Kumar, Anil	3	22
Laguir, Issam	3	47
Lee, C. K. M.	3	145
Min, Hokey	3	126
Rahimi, Yaser	3	136
Simic, Dragan	3	19
Sitek, Pawel	3	51
Stekelorum, Rebecca	3	47
Tavakkoli-Moghaddam, Reza	3	105
Wamba, Samuel Fosso	3	0
Wikarek, Jaroslaw	3	51
Zijm, Henk	3	57

Table 2-2: Most productive authors

The diagram in Figure 2-3 shows the top 10 countries with the highest number of publications based on a search in Web of Science containing the keywords “artificial intelligence”, “logistics” and “supply chains”. The results reveal that, out of the 375 collected publications, China has the highest number, with 84 papers accounting for 22% of the total records analyzed. Following China, France and the USA have the second and third highest numbers of publications, with 49 and 33 papers respectively. Collectively, these three countries account for 33% of the total records analyzed. It is important to note that the top ten countries account for 86% of the total records analyzed, indicating a concentrated distribution of research in this field. These findings suggest that China, France, and the USA are leading the way in terms of research on the topic of AI in logistics/supply chains, followed closely by a group of European countries, India, and Australia. Overall, the diagram provides an informative snapshot of current research trends in this field.

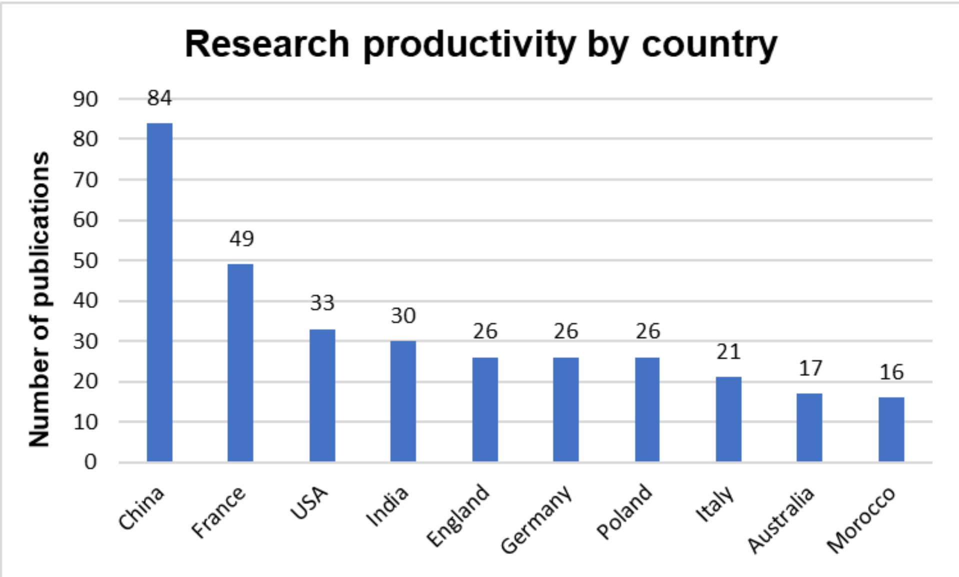

Figure 2-3: Research productivity by country

Rationale for utilizing bibliometric analysis in literature review/research

Bibliometric analysis is a valuable tool for conducting research in any field, and particularly for a study on the evaluation of different AI applications for operational logistic systems. By using the keywords "artificial intelligence", "logistics", and "supply chains" in the Web of Science database, a bibliometric analysis was conducted to identify relevant literature, understand research trends, and identify key authors and countries.

Firstly, the keyword analysis allowed for the identification of a set of publications that were highly relevant to the research question. This ensured that the literature review was focused and up-to-date, and that the most relevant research in the field was being considered.

Secondly, the publications by year analysis and source titles analysis provided an understanding of the research trends in the field. This allowed for the identification of gaps in the literature, or emerging areas of research that should be considered. Knowing which journals were publishing the most relevant research also allowed for targeted search efforts.

Finally, the most productive authors analysis and most productive countries analysis allowed for the identification of experts in the field and an understanding of where the research was being conducted. This information was valuable when it came to identifying potential collaborators or for understanding the cultural and institutional factors that may be influencing the research in the field.

Overall, utilizing bibliometric analysis is a valuable approach to steer literature review and research, particularly for the sections beginning from "3.3. AI implementations and trends in operational logistics" and beyond. Prior to this section, theoretical overviews and backgrounds on logistics and artificial intelligence are examined independently. Employing bibliometric analysis also guarantees that the thesis is rooted in the most up-to-date and pertinent research in the field.

2.2 Research structure

The research structure of the Thesis comprises several key components, starting with an information search that focuses on theoretical backgrounds of AI and operational logistics. The initial phase of the information search involves researching each topic separately to provide a theoretical overview of AI, its definition, and its different types. The focus then shifts to operational logistics, with an exploration of its definition, components, costs, strategic decision-making, trends, etc.

The next phase of the information search involves researching both topics in combination, examining AI implementations and trends in operational logistics, as well as the challenges associated with implementing them. This comprehensive approach enables the development of a solid theoretical framework that serves as the foundation for the research.

Following the establishment of the theoretical framework, the research then moves on to defining the evaluation criteria. This requires additional research to identify the most appropriate metrics for evaluating the different AI applications of a company. Once the evaluation criteria have been established, the next step involves creating the evaluation system itself.

The final research structure, therefore, comprises three key components: (1) an information search that explores the theoretical backgrounds of AI and operational logistics, (2) a research on the implementation challenges associated with combining these two fields, and (3) the development of an evaluation system for assessing the effectiveness of different AI applications in a company. By following this research structure, this master thesis aims to provide valuable insights into the potential benefits of using AI in operational logistics, as well as the most effective strategies for implementing and evaluating AI solutions.

2.3 Limitations

As with any research study, there may be certain limitations to the evaluation of AI systems in logistics that may arise during the research process. One potential limitation could be the scarcity of literature available on the topic. While there is a growing interest in the use of AI in logistics operations, it is possible that there may not be enough information available yet on the intersection of operational logistics and AI and, especially, on how to evaluate the effectiveness of these systems. As a result, the study may need to rely on a limited number of articles and sources in the development of the scoring system, which may impact its results. Another consequence of the limited availability of information on the specific topic we are investigating may be having to work with articles that contain potentially valuable information, even if they were not initially intended for the field of our research.

Another limitation could be related to the broad nature of the evaluation system. Since the study aims to provide a standardized and objective evaluation framework, the evaluation system must be general enough to apply to various AI-driven logistics systems. However, this may limit the specificity of the evaluation system and its ability to identify areas for improvement in a real-world scenario. Moreover, since the evaluation system is designed to be general, different perspectives may interpret the results differently.

While this may offer a broad view of the performance of AI-driven logistics systems, it may not provide a detailed analysis of specific strengths and weaknesses.

It is important to note that these are assumptions of potential limitations that may arise during the research process. It is crucial to carefully consider potential limitations throughout the research process and to use them as a starting point for future research. By doing so, it can ensured that the proposed evaluation system is as effective and accurate as possible, leading to more informed decision-making in the logistics industry.

3 Theoretical framework

3.1 Theoretical framework of AI

AI is defined as the computer's ability to independently solve problems that have not been explicitly programmed to be addressed. Alan Turing proposed in his article "Computing Machinery and Intelligence" back in 1950 the possibility of designing computers that can learn automatically and testing their intelligence [Tur-1950]. He suggested that humans use available information as well as reason in order to solve problems and make decisions, so machines might do the same thing too. The field of AI came to existence in 1956, in a workshop organized by John McCarthy, where they made an attempt to find out how to make machines use language, form abstractions and concepts, solve kinds of problems reserved for humans, and improve themselves [McC-1955]. In successive years they started to galvanize the field of "artificial intelligence". From 1957 to 1974, AI flourished. Computers could store more information and became faster, cheaper, and more accessible. Machine learning algorithms also improved and people got better at knowing which algorithm to apply to their problem. But breaching the initial fog of AI revealed a mountain of obstacles. The biggest challenge was the lack of computational power to do anything substantial after that: computers simply couldn't store enough information or process it fast enough. Since then, AI has had a slow growth with notable highlights such as the popularization of "deep learning" techniques which allowed computers to learn using experience, the introduction of expert systems which mimicked the decision-making process of a human expert, the first time a reigning world chess champion loss to an AI-driven computer, or the development of the first speech recognition software. However, the fundamental limit of computer storage that was holding us back 30 years ago is no longer a problem since the late 90s. Moore's Law, that estimates that the memory and speed of computers doubles every year, had finally caught up and in many cases, surpassed our needs. With the technological progress in designing computing power to store and process large dataset, the internet having the capacity to gather large amounts of data, and statistical techniques that can derive solutions from these datasets, allowed AI to emerge as one of the powerful technologies of the century. In the last two decades, technologies like computer vision, cognitive computing, context-aware computing, natural language processing, predictive analytics, machine learning, supervised and unsupervised learning, reinforcement learning, deep learning, etc. have enabled computers' "thoughts" by providing a conceptual framework for processing input and making decisions based on that data. [Kar-2018] [Any-2017]

3.1.1 Definition of AI

The European Comission define AI as follows: “Artificial intelligence (AI) refers to systems designed by humans that, given a complex goal, act in the physical or digital world by perceiving their environment, interpreting the collected structured or unstructured data, reasoning on the knowledge derived from this data and deciding the best action(s) to take (according to pre-defined parameters) to achieve the given goal. AI systems can also be designed to learn to adapt their behaviour by analysing how the environment is affected by their previous actions. As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimization), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems).” [Eur-2018]

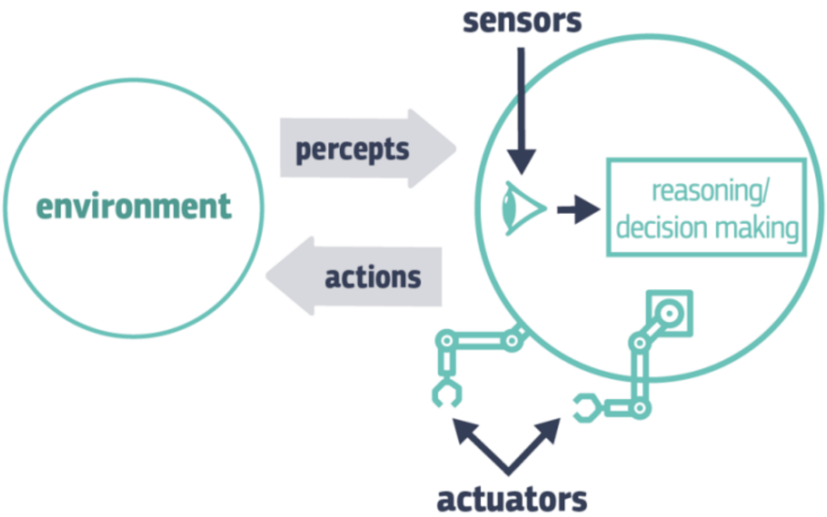

Figure 3-1: Illustration of an AI system

Figure 3-1 shows the illustration of an AI divided in its main components. It is a very simple abstract description of an AI system, through its three main capabilities: perception, reasoning/decision making, and actuation. [Eur-2018]

Perception

The system’s sensors, depicted as eyes in Figure 3-1, could be practice cameras, microphones, a keyboard, a website, sensors of physical quantities or other input devices that are adequate to perceive the data present in the environment that are relevant to the goal given to the AI system. As to what regards the collected data, it is often useful to distinguish between structured and unstructured data. Structured data is data that is organized according to pre-defined rules (such as in a database), while unstructured data does not have a known organization (such as in an image or a piece of text).

Reasoning/Decision-Making

The reasoning module is the core of an AI system. It takes as input the data coming from the sensors and outputs an action to take, given the goal to achieve. This means that the data collected by the sensors must be transformed into information that the reasoning module can understand. In Figure 3-1, the camera (sensor) will provide a picture of the situation, for example, and this module must decide what is the best action to achieve the desired goal.

Actuation

The actuators available on the AI system then perform the action that has been decided upon. In Figure 3-1, the actuators are represented as arms and legs, but they don't need to be physical. The actuators could also be software. The action performed is going to possibly modify the environment, so the next time the system needs to use its sensors again to perceive possibly different information from the modified environment. Rational AI systems modify the environment but they do not adapt their behavior over time to better achieve their goal. They do not always choose the best action for their goal, thus achieving only bounded rationality, due to limitations in resources such as time or computational power. A learning rational system is a rational system that, after taking an action, evaluates the new state of the environment (through perception) to determine how successful its action was, and then adapts its reasoning rules and decision-making methods. [Eur-2018]

3.1.2 Types of AI

There are three main groups of AI techniques or sub-disciplines we are going to discuss that are currently used to build AI systems: two main groups that refer to the capability of reasoning and machine-learning and, on top of them, we also have robotics. Figure 3-2 depicts the AI sub-disciplines mentioned, as well as their relationship. It is important however to notice that AI is much more complex than what this illustration shows, since it includes many other sub-disciplines and techniques.

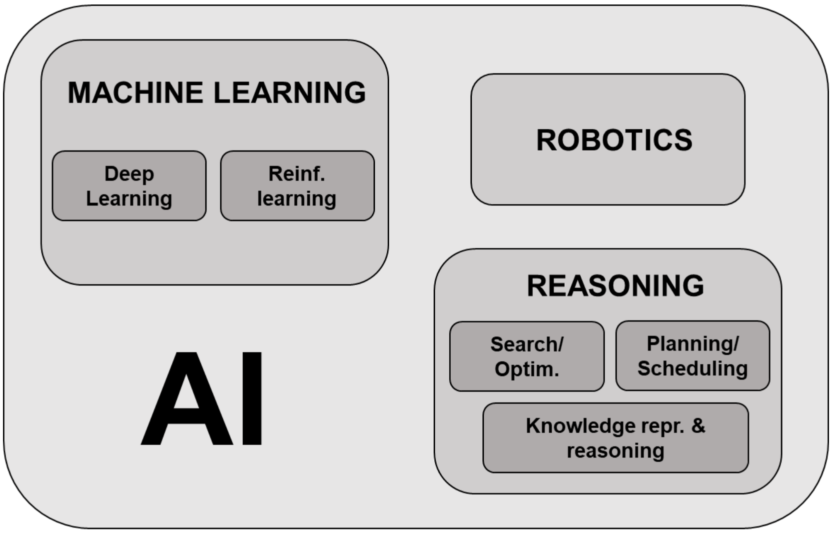

Figure 3-2: AI's sub-disciplines

Reasoning and Decision-Making

This group of techniques includes knowledge representation and reasoning, planning, scheduling, search, and optimization. These techniques allow to perform the reasoning on the input data coming from the sensors. In order to do this, data has to be transformed into knowledge, so one area of AI has to deal with how best to model such knowledge (knowledge representation). Once knowledge has been modelled, the next step is to reason with it (knowledge reasoning), which includes making inferences, planning and scheduling activities, searching through a large solution set, and optimizing among all possible solutions to a problem. The final step is to decide what action to take. The reasoning/decision-making part of an AI system is usually very complex and requires a combination of several of the above-mentioned techniques.

Learning

This group of techniques includes machine-learning, neural networks, deep learning, decision trees, and many other learning techniques. These techniques allow an AI system to learn how to solve problems that cannot be precisely specified, or whose solution method cannot be described by symbolic reasoning rules. Examples of such problems are those that deal with perception capabilities such as speech and language understanding, as well as computer vision. These problems are apparently easy, because they are usually easy for humans. However, they are not that easy for AI systems, since they cannot rely on common sense reasoning (at least not yet) and are especially difficult when the system needs to interpret unstructured data. This is where techniques that follow the machine-learning approach come in handy. However, machine learning techniques can be used for many more tasks than only perception. The most wide-spread machine-learning approaches are supervised learning, unsupervised learning, and reinforcement learning.

Supervised learning is a machine-learning approach defined by its use of labeled datasets. These datasets are designed to train or “supervise” algorithms into classifying data or predicting outcomes accurately. Using labeled inputs and outputs, the model can measure its accuracy and learn over time. Instead of giving behavioral rules to the system, we provide it with examples of input-output behavior, hoping that it will be able to generalize from the examples and behave well also in situations not shown in the examples.

Unsupervised learning uses machine learning algorithms to analyze and cluster unlabeled data sets. These algorithms discover hidden patterns in data without needing human intervention (that’s why they are “unsupervised”). Unsupervised learning models are used for three main tasks: clustering, association and dimensionality reduction.

In supervised learning, the algorithm “learns” from the training dataset by iteratively making predictions on the data and adjusting for the correct answer. While supervised learning models tend to be more accurate than unsupervised learning models, they require upfront human intervention to label the data appropriately. Unsupervised learning models, in contrast, work on their own to discover the inherent structure of unlabeled data. In supervised learning, the goal is to predict outcomes for new data. The type of expected results are already known. With an unsupervised learning algorithm, the goal is to get insights from large volumes of new data. The machine-learning itself determines what is different or interesting from the dataset. [Del-2021]

Some machine learning approaches use algorithms based on the concept of neural networks, which is inspired by the human brain since it has a network of small processing units (analogously to our neurons) with lots of weighted connections among them. A neural network has as input the data coming from the sensors and as output the interpretation of the picture. During the analysis of the examples (the network’s training phase), the connections’ weights are adjusted to match as much as possible what the available examples say (that is, to minimize the error between the expected output and the output computed by the network). At the end of the training phase, a testing phase of the behavior of the neural network over examples never seen before checks that the task has been well learnt.

There are several kinds of neural networks and machine learning approaches. Currently one of the most successful one is deep learning. This approach refers to the fact that the neural network has several layers between the input and the output that allow to learn the overall input-output relation in successive steps. This makes the overall approach more accurate and with less need of human guidance. It begins in the first level with a layer of input neurons. These record the data, start analyzing it and send their results to the next neural node. Eventually, the more and more refined information reaches the exit level, and the network outputs a value.

Reinforcement learning is another useful kind of machine learning approach where the AI system makes its decisions, over time, and at each decision we provide it with a reward signal that tells it whether it was a good or a bad decision. The goal of the system is to maximize the positive feedback received. Reinforcement learning differs from supervised learning in a way that in supervised learning the training data has the answer key with it so the model is trained with the correct answer itself. In reinforcement learning, there is no answer but the reinforcement agent decides what to do to perform the given task. In the absence of a training dataset, it is bound to learn from its experience.

Since many AI systems, such as those including supervised machine learning components, rely on huge amounts of data to perform well, it is important to understand how data are influencing the behaviour of the AI system. For example, if the training data is biased (not balanced or inclusive enough), the AI system trained on such data will not be able to generalize well and will possibly make unfair decisions that can favour some groups over others. Recently the AI community has been working on methods to detect and mitigate bias in training datasets and also in other parts of an AI system.

Robotics

Robotics, also called “embodied AI”, can be defined as “AI in action in the physical world”. A robot is a physical machine that has to deal with the uncertainties, the dynamics and the complexity of the physical world. Perception, reasoning, action, learning, as well as interaction capabilities with other systems are usually integrated in the control architecture of the robotic system. In addition to AI, other disciplines play a role in robot design and operation, such as mechanical engineering and control theory. Examples of robots include robotic manipulators, autonomous vehicles (e.g. cars, drones, flying taxis), humanoid robots, robotic vacuum cleaners, etc. [Eur-2018]

3.2 Theoretical framework of operational logistics management

As customers, many people tend to ignore the direct or indirect effects of logistics on almost every sphere of their lives until one of these “rights” goes wrong. The logistics concept was introduced as a response to the increasing necessity of an integrated system, which plans and coordinates the materials flow from the source of supply to the point of consumption instead of managing theses flows as series of independent tasks. Companies adopt numerous business improvement methodologies in order to upgrade their business performance and logistics, as well as supply chain management. It has been considered to be the crucial factor for the organizations to gain competitive advantages. [Li-2014]

Today, experts in logistics perform their duties based on their skills, experiences, and knowledge. In modern industries, the task of logistics managers is to provide appropriate and efficient logistics systems. They guarantee that the right goods will be delivered to the right customers, at the right time, at the right place, and in the most economical way. Although logistics is a dilemma for many companies, logistical science can bring some relief to them. In today’s business environment, logistics is a competitive strategy for the companies that can help them meet the expectations of their customers. Logistics helps members of supply chains integrate in an efficient way. Logistics does not consist of one single component but involves a group of various activities and disciplines such as purchasing, planning, coordinating, warehousing, distributing, and customer service. [Far-2011]

It is stated that the concept of logistics has existed for centuries. First, the concept was found in military applications. Over time, and because of different changing periods, the appeal to logistics moved into the mainstream business area. There have been found numerous definitions for logistics, which will be discussed in this chapter, and most of them refer specifically to the physical movement and storage of materials.

3.2.1 Definition of logistics and logistics management

Selon Henk Zijm et al., logistics refers to the transportation and storage of materials, parts and products in a supply chain. Logistics includes inbound and outbound processes to and from warehouses, as well as internal and external materials handling and transport operations. It also includes the execution of services and the transfer of information between the various stages of a supply chain. [Zij-2019]

According to Martin Christopher, logistics can be defined as the process of strategically managing the procurement, movement and storage of materials, parts and finished inventory (and the related information flows) through the organization and its marketing channels in a profitably way referring to current and future actions and this through cost-effective fulfilment of orders. [Mar-2016]

The Council of Supply Chain Management Professionals (CSCMP) defined the logistics management as that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements. Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. A proper execution of logistic operations depends on, and has impact on, sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. Logistics management is an integrating function, strongly relying on an adequate information infrastructure, and ideally synchronized with other functions including marketing, sales, manufacturing and finance. [Cou-2013]

3.2.2 Components of logistics systems

The entire process of logistics, which deals with the moving of materials into, through, and out of a firm, can be divided into three parts: Inbound logistics involves the movement and storage of materials received from suppliers, materials management encompasses the storage and movement of materials within the company and is the focus of this study, and outbound logistics, also known as physical distribution, refers to the movement and storage of products from the final production stage to the customer.

This division of inbound, materials management, and outbound logistics is depicted in Figure 3-3.

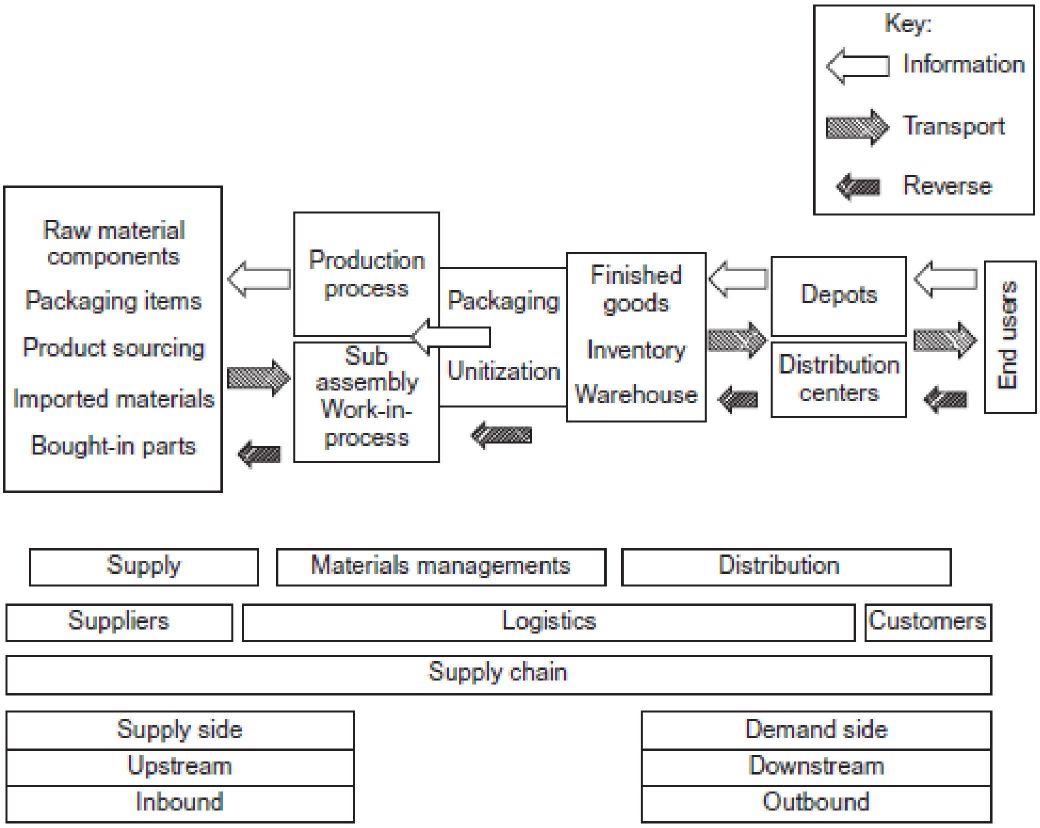

Figure 3-3: Logistics flows and terminologies

Figure 3-3 also shows the two types of flow logistics is concerned with: physical flow and information flow. The physical flow is depicted as the forward flow throughout the logistics network, the main direction of which is from the point of origin to the point of consumption, since it is its common direction. And the information flow is depicted as the backward flow, from downstream to upstream elements. However, in practical terms, the directions of physical and information flows are not one way. Materials and information flow from both upstream and downstream. Regarding physical flow, the backward flow of product is referred to as reverse logistics. It is the flow of returned goods and used products as well as salvage, scrap disposal and returnable packaging back through the system.

The major components of logistics systems can be categorized the five functional areas "transportation", "inventory", "warehousing, material handling and packaging", "information and control" and "network design".

Transportation

A transportation system is an organization that designs, arranges, sets up and schedules freight-transportation orders during a given time period with technical restrictions at the lowest possible cost. Transportation systems move goods between origins and destinations using vehicles and equipment such as trucks, tractors, trailers, crews, pallets, containers, cars or trains. They are essential for moving any shipment in a logistic system such as raw materials from sources to manufacturer, semifinished products between plants, and final goods to retailers and customers.

Transportation represents the major role and most important element in logistics because of its considerable cost. These days, the growth of science and technology, increasing consumption, market uncertainty and global commerce highlight the role of transportation in all processes. There is a high level of competition between manufacturers and also transportation holders in the cost and quality of their customer services. Critical competitive factors and main objectives of every logistics system are reducing lead times, delays, and whole transportation costs, as well as increasing efficiency, reliability, safety, and reactivity in their service systems. To do this, taking advantage of the latest technologies and managing to implement them in the logistics system is an important key to such differentiation.

Transportation systems are among the most complex organizations and involve many components such as human and material resources, complex connections, and balances between decision variables and management policies that directly or indirectly affect different components of the system. To decrease this complexity, researchers have provided a general classification for transportation problems with the three main planning levels: strategic, tactical and operational planning. Strategic planning involves decisions at the highest level of management and requires long-term investment. Strategic decisions develop general policies and extensively structure the functional strategies of the system. Any physical changes or development in the whole network such as locating main facilities (hubs and terminals for example) are examples of strategic decision planning. Tactical planning needs medium term investment and is not as critical as strategic planning. This class contains a well-organized allocation and operation of resources to improve system performance. Examples of this category are decision making in the design of service networks, service schedules, repositioning fleets, and traffic routing. Operational planning deals with short term and urgent decision making performed by local management, yard masters, and dispatchers. Decisions at this level do not need large investments. The completion and adjustment of schedules for services, crews, maintenance activities, and routing and dispatching of vehicles and crews are examples of this category.

Warehousing and storage

Warehousing is another crucial aspect of logistics, closely tied to the physical flow of goods. Although maintaining inventory can incur high costs, accounting for 25-40% of logistics expenses, companies still keep stocks for several reasons. These reasons include safeguarding against fluctuations in customer demand and lead times, utilizing economies of scale in purchasing, transportation, and production, balancing supply and demand disparities, protecting against unexpected disruptions such as strikes, fires, and floods, removing manufacturing limitations for increased efficiency, and hedging against sudden price changes by holding onto cost-effective raw materials.

Therefore, warehousing has become an important part of companies' logistics systems, which stores goods at and between the origin and destination points and provides the management with information about the status, disposition, and condition of inventories. These inventories can be categorized into physical supply (raw material, components and parts), physical distribution (finished goods), and goods in process.

Warehousing plays a critical role in logistics systems, providing the desired customer-service levels in combination with other logistics activities. A wide variety of operations and tasks are performed in warehousing. These can be categorized under three basic functions: movement or material handling, storage and information transfer.

Movement or material handling is a crucial function within logistics and involves four primary activities: receiving and put away, order filling or order picking, cross docking, and shipping. Receiving and put away involve unloading goods from transportation equipment, verifying their count and specifications against order records, inspecting them for damage, and updating warehouse inventory records. Order filling or order picking entails identifying and retrieving products from storage locations based on customer orders. This process also involves grouping, accumulating, and packaging the products into the desired assortment for customers, and may include generating packing slips or delivery lists. Cross docking involves unloading materials from the manufacturer or transportation directly to the customer or another mode of transportation with minimal to no storage in between. Finally, shipping involves moving and loading assembled orders onto transportation carriers, checking the contents and sequence of orders, and updating inventory records. This may also include sorting and packaging products for specific customers, as well as bracing and packing items to prevent damage.

The storage function of warehouses is simply about the inventory accumulation over a period of time. The storage of inventory may take place in different locations and for different lengths of time in warehouses, depending on the storage purpose. According to the length of storage time, one can differentiate between temporary (short-term) or semipermanent (long-term) storage. In temporary storage, only products required for basic inventory replenishment are stored. The amount of temporary inventory required to be stored in warehouses is determined based on the extent of variability in lead time and demand. Also, the design of logistics systems may affect the inventory extent. The emphasis of temporary storage is on the movement function of warehousing, and pure cross docking tends to use only this kind of storage. However, semipermanent or long-term storage includes the storage of products in excess of that necessary for basic replenishment and is used, for example, when seasonal or erratic demand is given, conditioning of products is necessary or special deals (quantity discounts) are dealt with.

The information transfer function takes place concurrently with the other warehousing functions (movement and storage) and provides the warehouse manager with information on the inventory and throughput levels locations where products are stored, as well as inbound and outbound shipments. These types of information along with the data on space utilization, customer and personnel information, and other pertinent information are essential for ensuring a successful warehousing operation. Companies are constantly improving the speed and accuracy of their information-transfer function by implementing new technologies into their systems.

Material handling

Storage and handling systems fall into two main categories: palletized and non-palletized.

Wooden pallets are the most frequently used unit load in warehouses mainly because they allow the use of standard storage and handling equipment, regardless of the size and characteristics of the goods on the pallet. Products in these types of systems either arrive on pallets or are palletized at the receiving areas, so they can benefit from the convenient size load for their movement and storage. Some of the most regular types of equipment for horizontal movement of pallets in warehouses are pallet trucks (powered or non-powered), tow and platform trucks, conveyors or automated guided vehicles (AGVs). To place pallets on top of each other and store them in storage racks, so the warehouse space is utilized more efficiently, equipment capable of lifting pallets or loads (stacking) is employed. Some examples of the following stacking equipment and lifting trucks may also be used to horizontally transport loads around the warehouse: counterbalanced forklift trucks, pallet stackers, reach trucks, specialist pallet stacking equipment, etc.

However, there are many types of products that cannot be palletized because of their special characteristics: too large, too long, having handling limitations… A wide range of attachments are available for fitting to forklift trucks so that they can handle goods that cannot be touched by forks. These truck attachments enable additional degrees of movement for handling unit loads. The extra weight of these attachments should be considered in calculating the payload capacity of trucks and in determining the weight that can safely be carried by the truck though. Cranes are commonly used for handling very heavy loads, such as metal bars, or for relatively lighter loads that are just too heavy to be handled manually. Cranes can provide movement of loads only in limited and predetermined areas and some typical examples are bridge cranes, gantry cranes, jib cranes or stacker cranes. They are electrically powered and they may be used with attachments like hooks, magnets, mechanical clamps, etc.

Conveyors were already briefly introduced under the equipment for horizontal movement of pallets. They are widely used in warehousing to move both palletized and non-palletized loads over fixed routes. Conveyors may also be used to sort or accumulate products (short-term buffering) or as an integral part of packaging and order-picking operations. In comparison to powered conveyors, gravity conveyors are more basic and less costly. They are normally used to move loads weighing up to several tons over short distances and accumulation at the end is provided. The major types of gravity conveyors are spiral chute conveyors, wheel conveyors and gravity roller conveyors. Powered conveyors are normally used for moving heavier loads or goods with irregular shapes over longer distances or paths with inclines. Some of the more frequently used types include the following: belt conveyors, live roller conveyors, slat conveyors, chain conveyors and trolley conveyors.

AGVs were also introduced under the equipment for horizontal movement of pallets. In addition to palletized loads, AGVs may be used for moving non-palletized loads, especially large and heavy loads, including paper reels and automobile bodies. There exists a wide range of AGV types, and they can be guided using physical guide path or by nonphysical guide path (software).

Inventory

Inventories are raw materials, work in process, and finished goods that companies keep for different reasons such as saving time, to meet economic objectives, or as a buffer against uncertainties. The basic element of customer service for all logistics is inventory availability, and this is the most expensive logistics cost. Effective inventory management decreases carrying cost and increases customer satisfaction at the same time.

The different types of inventories that can be stored in a warehouse include cycle stock, safety stock, transit inventory, speculative stock, seasonal stock, and dead stock. Cycle stock refers to inventory with a highly predictable turnover that needs to be replenished regularly. Safety stock serves as a buffer against demand and lead time uncertainty, compensating for fluctuations in these areas. Transit inventory is composed of products that are being transported between the producer and the purchaser and are not yet ready for use or sale. It represents the expected demand over the lead time, which is the time between placing an order and receiving it. Speculative stock is kept in anticipation of potential material shortages, price increases, or unexpected changes in demand, rather than to meet current demand. Seasonal stock is a type of speculative stock that is held to meet anticipated demand during a specific time period. Finally, dead stock refers to inventory that is no longer in demand.

Inventory control is the set of activities that coordinate purchasing, manufacturing, and distribution to maximize the availability of raw materials for manufacturing or the availability of finished goods for customers. Warehouse management should consider three basic questions for inventory control: what items should be kept in stock (so that they provide benefits), when should an order be placed, and what order size should be ordered.

Information, control and communication technology

The emergence of new technologies leads to a change in the practice and significance of logistics management and emphasizes its role in strategic function of companies. By involving new technologies in logistics operations, the role of logistics in organizations changed from only a supportive function to a value-added function, and companies can achieve better customer service and higher cost savings so that they can compete in global markets.

Information and communication systems and technologies can play different roles in supply-chain and logistics management. These systems and technologies can be applied to data gathering and analyses, support decision makers, control and monitor supply-chain operations, use information for forecasting, and facilitate the communication between supply-chain members. The information flow in a logistics system is as important as material flow, and information is considered as a key source in logistics system. When the complexity of logistics systems and channels increases and more members become involve, the role of information flow in the logistics system becomes more significant.

In a logistics system, different types of activities and internal or external processes generate data. The major purpose for collecting, retaining, and manipulating this data within a company is to make decisions ranging from the strategic to the operational and to facilitate a business's transactions.

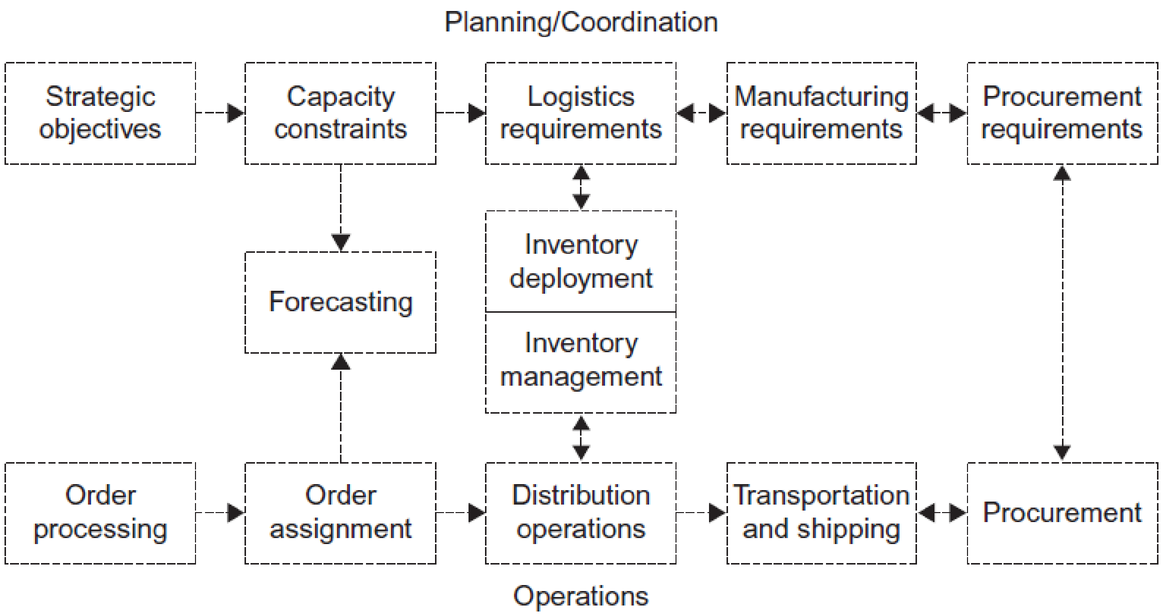

Figure 3-4: Logistical information components

As shown in Figure 3-4, logistical information has two major components: planning/coordination, and operations.

The primary drivers of supply-chain operations are strategic objectives derived from marketing goals (customer bases, breadth of products and services, and promotions) and financial goals (required resources to support inventory, receivables, equipment, capacity, etc.). Capacity constraints identify manufacturing and market-distribution limitations, barriers, or bottlenecks. The output of capacity constraint planning is time-phased objectives that detail and schedule facility utilization, financial resources, and human requirements. logistic requirements identify the specific work facilities, equipment, and labor forces required to support the strategic plan. Logistics requirements must be integrated with both capacity constraints and manufacturing requirements to achieve the best performance. Inventory deployment interfaces with inventory management between planning and coordination and operations. The deployment plan details the timing of where inventory will be positioned to efficiently move inventory through the supply chain and the inventory management is performed on a day-to-day basis. In production situations, manufacturing requirements determine planned schedules and procurement requirements represent a time-sequenced schedule of material and components needed to support manufacturing requirements. Forecasting is the prediction of the future using historical data, current information, and planning goals and assumptions and its challenge is to quantify expected sales for specific products.

A second purpose of accurate and timely information is to facilitate logistical operations. To satisfy supply-chain requirements, logistics must receive, process, and ship inventory. The overall purpose of operational information is to facilitate integrated management to market distribution, manufacturing support, and procurement operations. Planning and coordination identify and prioritize required work and identify operational information needed to perform the day-to-day logistics.

There is a large number of IT technologies that make accurate capture, storage, and distribution of information within supply chains. They are called data-handling hardware and the following describes a few of the most popular techniques.

Bar coding facilitates the tracking of goods moving through the logistics system, especially in warehousing operations such as goods receiving, stock checking, finding storage locations, and dispatching. Generally, bar code systems are used to identify logistics system elements such as the identification of goods, containers, documents, production, location, and equipment. This technology is reliable, fast and cheap, but does not save a large amount of information.

Radio frequency identification (RFID) is a technology that allows objects to be tagged with a device that contains a memory chip. The chip has a read-and-write facility that is currently executed using a variety of radio frequencies. This allows every individual item to be uniquely identified passing through an arch-shaped reader, for example, something bar codes could never practically do. The time, labor, and potential errors associated with carrying out numerous manual scans of a bar code on its journey through a particular process or part of the supply chain, for example, can all be solved by using RFID because RFID tags are automatically read whenever they are in proximity to a reader. The total number of possible reads for a product through a system makes the cost lower and lower over time, making the technology more economical and polyvalent.

Magnetic stripes are used to store a large quantity of information in a small space and data contained in the stripe can be changed. The stripes must be read by physical contact, which prevents this technology from being used in high-speed sorting applications. In warehousing, magnetic stripes are used on smart cards capturing information ranging from employee identification to the contents of a trailer load of material to the composition of an order-picking tour.

Vision system cameras take pictures of objects and codes and send the pictures to a computer for interpretation. Vision systems “read” at moderate speeds with excellent accuracy for limited environments. However, the accuracy of a read is highly dependent on the quality of light.

Geographical information system (GIS) and global positioning system (GPS) are well-known technologies ordinarily used in transportation and distributions. GPS is a satellite-based navigation system, and GIS is used to capture, store, analyze, manage, and present data that are spatially referenced (linked to location).

A Logistics Information System (LIS) represents an integration of data, supporting equipment, and personnel and problem-solving methods that are used to assist the logistician in planning and operations. It is a computer-based information system that coordinates and manages all logistics management activities. Such an LIS must be capable of transferring information between the source and demand points. The LISs have three main components: input, database, and output.

The input phase is a collection of data sources and data-transfer methods and means for making appropriate data available to the computing portion of the system. The LIS data can be obtained from many sources and in many forms, particularly from customers, company records, published data or management predictions.

The most important component of an information system is database management, converting module in which data is converted to information and information is converted to useful knowledge for decision making. It contains three main functions: data selection, analysis method selection, and basic data-processing procedure to implement.

The outputs of an information system are the interface with the user of system. These outputs are represented in form reports, prepared documents, and results of data analysis from mathematical and statistical models. [Far-2011]

3.2.3 Logistics costs

Logistics is one of the many factors generating costs in a firm, which significantly contributes to the financial position of enterprises. The concept of cost always accompanied each business activity, and logistics constitutes an important part of entrepreneurial activity, which implies the possibility of a systematic cost reduction in the company. Reducing these costs has become an increasingly important task for managers. A slight reduction in costs may be decisive in maintaining a competitive position on the market by the company. [Stę-2016]

Logistics costs are understood as expenses incurred from performing logistics activities, and from having the infrastructure, capacity or the readiness to perform logistic activities during a certain period of time [Rav-2017]. Selon Gudehus & Kotzab, the total company logistic costs comprise all logistics costs between the receiving ramps of the company and the receiving ramps of their customers. [Gud-2012]

Logistics costs components by activities

A typical supply chain management perspective is to classify logistics costs across activities or through chain functions in transportation, inventory-related, administrative and customer-related costs.

Transportation costs are the dominant consideration, since they account for more than half of the logistic costs. They include the costs related to the operation and maintenance of transportation modes and terminals used in the supply chain. They are the costs related to moving goods between where they are manufactured and where they are distributed and consumed [Rod-2020]. It can be distinguished between company internal (e.g. transport from one warehouse to another) and external transportation;

transportation with own fleet and third party transport services; and regular and as-needed transport. [Rav-2017]

Inventory-related costs are made up of inventory carrying costs and warehousing costs. Inventory carrying costs are the variable costs of maintaining inventory in a warehouse. They include the costs of holding goods in inventory (capital costs, labor, warehousing, depreciation, insurance, taxation, risk costs and obsolescence) as well as the physical handling of goods, including tasks such as packaging and labeling. Inventory carrying costs vary according to the volume handled and are commonly expressed as a share of the inventory value. Warehousing costs are the fixed costs of owning or leasing warehousing space, including maintenance and utilities. They vary according to the number and the size of facilities and are irrespective of the amount of inventory being handled. [Rod-2020]

Administrative costs include managerial overheads such as order processing order, communications, forecasting, managing the workforce, etc. They also include information technologies such as computer equipment and software.

One of the major customer service costs at this level is the cost of lost sales. Another example in this category is the cost of returned goods. [Ako-2018]

Logistics costs components by cost types

Another way of classifying logistics costs is by cost type. This corresponds to the accounting perspective. Cost information is likely to be classified in the accounts of many companies in labor, facilities, running and depreciation costs.

Personnel or labor cost forms a big part of the total logistics costs, whether in the purely operative logistics task in warehouse or in logistics administration. Warehouse staff may be outsourced in many organizations, in order to make this cost group more variable with the volume handled.

Facilities costs include the buildings used for logistics activities, either leased or owned. Land cost may be included in this or be a separate item. Equipment includes the shelving, forklifts, pallets, and other equipment used for logistics operations. IT-systems and computers may be a part of this or belong to a separate category.

Running costs include items such as fuel, electricity, water, maintenance, insurance, telephone expenses, printing and photocopying etc.

Depreciation of logistics assets (buildings, machinery and transportation fleet) is also an expense influencing the profit-loss statement. Different companies may use different depreciation methods, which affects the comparability of logistics costs between companies. [Ako-2018]

3.2.4 Logistics strategic decisions

Strategic decisions are business objectives and mission statements, as well as marketing and customer-service strategies. Therefore, they are long-term kinds of decisions made over one or more years. The data at hand for such decisions are often imprecise, incomplete, and need forecasts. Strategic decisions are made to optimize the capital reduction (level of investment, which depends on owned equipment and inventories), the cost reduction (total cost of transportation and storage), the customer satisfaction and the order cycle time.

Depending on the type of business, logistics decision groupings are diverse. However, all of these decision categorizations comprise the following three basic types of strategic decisions: customer service, logistics network design and outsourcing versus vertical integration. Since customer service is related to outbound logistics and the focus of this study is on material handling within the firm, the last two types of decisions will be explained below.

Logistics network design

The structure and flow of materials and information of a company must be appropriate in order to achieve corporate strategies. Here, we will take a look at physical and information network strategies, the two main groups logistics network design is divided into.

Physical facility location is about determining the number, size, location, and necessary equipment of new facilities together with alteration of existed ones. In many facility location decisions, allocation decisions are also included. The usual objective of such decision problems is minimizing total system costs, but some businesses, particularly those in public sectors, consider maximizing the service level or even balancing both objectives. Facility location decisions are made at the start of a business, but also with a long-term view in mind. Since the demand trends change, system changes should be reconsidered over time.

Decisions related to communication and information network are about the establishment and maintenance of an effective communication system and planning for information sharing throughout the system. Centralizing or distributing the information, the technology used for such system, integration of the information flow (such as the use of enterprise resource planning or ERP systems), standardization of hardware, software, development environment, vendors, and the role of e-commerce are some of most important decisions made in this category.

Outsourcing versus Vertical Integration

Outsourcing decisions determine which functions should be outsourced, as well as the nature and extent of outsourcing agreements. When a firm is unable to build an item (especially a routine one) or is uncertain about the volume required and suppliers offer favorable costs or have specialized research on the job, then outsourcing the job to a third party might be a good option. Some advantages related to outsourcing are greater flexibility, lower investment risk, improved cash flow, and lower potential labor costs. However, the business might lose control over its process, might have long lead times or shortages, or choose the wrong supplier.

Vertical integration (also known as insourcing) is preferred when the firm wants to integrate plant operations, needs to have direct control over production and quality, desires some secrecy, lacks reliable suppliers, or has items or production technology that is strategic to the firm. Decisions on vertical integration have higher control over inputs, higher visibility over the process, and so on. However, more integration requires higher volume and higher investment, and there is less flexibility in using equipment.

Tools of strategic decision making

The most applicable tools for strategic decision making can be classified into benchmarking, optimization programming, simulating and forecasting.

Benchmarking deals with comparing the performance of a logistics system to a best-practice standard (e.g., a successful logistics firm). Another use of benchmarking is auditing the performance of the competitors in the market and finding their gaps in serving customers.

Like many decision-making problems, most logistics strategic problems can be stated as mathematical problems. Unfortunately, these optimization problems are among nondeterministic polynomial-time hard problems, which has resulted in the development of fast heuristic algorithms. These algorithms are intended to search the solution space for good but not necessarily the optimal solutions.

Simulation evaluates the behavior of the system or a particular configuration under different alternative conditions. These conditions are set one by one for every simulation run, and the results show the probable reaction of the system to these scenarios. With this tool, managers can evaluate their strategies and decisions before spending capital, building facilities, and establishing their logistics system. A technology that is gaining considerable importance in logistics in recent years is called Digital Twin (DT).

DTs can be defined as (physical and/or virtual) machines or computer-based models that are simulating or ‘‘twinning’’ the life of a physical entity, which may be an object, a process, a human, etc. A DT is a living, intelligent and evolving model, being the virtual counterpart of a physical entity or process that follows the lifecycle of its physical twin to monitor, control, and optimize its processes and functions. It continuously predicts future statuses (defects, failures for example) and allows simulating and testing novel configurations, in order to preventively apply maintenance operations. [Bar-2019]

Forecasting means an attempt to determine in advance the most likely outcome of an uncertain variable. Logistics requirements to be predicted might be customer demands, raw material prices, labor costs and/or lead times. Qualitative forecasting methods are most likely surveys, market research, the Delphi method, and sales-force assessment. Quantitative forecasting methods are casual methods based on past and current data (regression, econometric models, input-output models, life-cycle analysis, computer simulation models, etc.) and time-series extrapolation (elementary techniques, moving averages, exponential smoothing techniques, etc.).

Logistics strategic flexibility

In the current uncertain and rapidly changing business climate, managers must monitor these changes and prepare their organization to respond and even take advantage of them. This proactive ability is called strategic flexibility. Logistics managers should have a complete knowledge of the life cycle of a product and the role of market changes in the life cycle so that they can respond to changes and decide when to abandon or improve the product. Strategic flexibility needs to be evaluated and measured in terms of three major dimensions: speed of change, cost of change, and amount of change. [Far-2011]

3.2.5 Logistics philosophies

Lean logistics

Lean methods and concepts in production and logistics have been changing logistics processes in the automotive industry worldwide since they were developed in the 1940s at Toyota in Japan. Not a theoretically sound concept forms the basis here, but a methodology developed over decades and constantly refined on the basis of operational experience and investigations in the automotive industry.

The goal of lean logistics is to create a high-performance logistics system which, on the one hand, meets the high productivity requirements of manufacturing and, on the other hand, is the source of strategic competitive advantages through short lead times with high flexibility. Lean Logistics optimally links and coordinates the customer-oriented value creation processes of a lean factory. Lean logistics is understood to be synchronized, flow-oriented and clocked logistics that is retrograde and pull-oriented to customer requirements. It is also characterized by stable and lead-time-optimized logistics activities, with the help of which the high productivity of a lean factory can be realized. of a lean factory can be realized.

A basic requirement for a successful implementation of lean philosophy is the sustainable avoidance of waste of all kinds in the company. According to Toyota, a distinction is made between seven (plus one) types of waste (“muda”) (Figure 3-5 [Skh-2017]). Waste refers to anything except the minimum expenditure for resources, materials, parts, space and working time, which is essential for increasing the value of a product. [Klu-2018]

Figure 3-5: The eight wastes of lean

The following basic principles of Lean Logistics are characterized by their general validity, even if their implementation is company- or plant-specific to each company or trade. [Klu-2018]

The coordination of material flows in terms of time and quantity between the individual components of a logistics network is the main requirement of synchronized lean logistics. The aim of synchronization is to fulfill every customer order within the specified time and cost targets. By synchronizing the production and the logistics processes, the activities of the value-adding process are determined exactly according to market requirements, thus enabling production to be carried out in close proximity to the customer. Logistics synchronization means that the areas of program planning and the assembly and parts supply process are closely interlinked. This makes it possible to sustainably reduce inventories, avoid overproduction, increase process reliability and product quality, and improve the level of service. The more synchronized the logistics processes, the shorter the lead times and the lower the average inventory levels in the company. The pacing principle serves as the pacemaker for the synchronization processes.

The takt serves as a rhythm and impulse generator for all production and logistics processes in the company. The starting point for the takt calculation is the customer takt, which represents the heartbeat of all logistics activities in the company. The customer takt is a reference figure which is used to adjust the production or logistics rate to the sales rate and is calculated by dividing the available net production time per planning period by the production volume in vehicles per planning period. All material flows in the company are coordinated with each other using the takt principle. Although the takt can be adjusted periodically according to customer demand, it must remain unchanged at a fixed takt level during the planning period (e.g., shift). This enables logistics to adjust to specific quantity and flexibility requirements, which means that avoids safety stocks, safety areas and waste.

The logistical flow principle between the activities, i.e., the continuous movement of all materials and finished products, forms the top maxim. A steady production flow therefore requires that, in addition to the value-adding operations, the logistics processes are also mutually coordinated. Reorganization of production according to the principles of flow production forms the basis of flow-optimized logistics and consequently requires simultaneous planning of the production and logistics processes. The ideal goal of flow-optimized production and logistics is the so-called one-piece flow system. One-piece flow means that parts are moved through operations from step to step with no work-in-process (WIP) in between either one piece at a time or a small batch at a time. This system works best in combination with a cellular layout in which all necessary equipment is located within a cell in the sequence in which it is used. Achieving one-piece flow helps manufacturers achieve true just-in-time manufacturing, that is, the right parts can be made available when they are needed in the quantity they are needed.

The pull philosophy for material handling means that material is only provided, transported and handled when there is a demand from the downstream logistics point. This means that material is not pre-produced on the basis of a (usually inaccurate) forecast, but only what is really needed in a timely manner. Ideally, the customer order extends along the entire logistics chain, so that all distribution, production and procurement stages are traded according to customer requirements within the framework of a build-to-order strategy. By applying the pull principle, capital-intensive inventories and circulating stocks can be reduced to a minimum, so that only small safety buffers are needed for efficient and waste-free production.

In addition to achieving high and consistent quality, standardization also leads to a unification and simplification of logistics processes. The creation of standards makes it possible to avoid special processes that always require more resources. The goal is to cover current logistics processes in the company as far as possible with predefined standard procedures, which are documented in so-called standard worksheets as a best practice solution.

All the basic principles listed so far, such as synchronization, takt, flow, pull and standard, together lead to stable and robust logistics processes. Calm and stable material flows result in an increase in the company's ability to plan while simultaneously reducing the susceptibility of logistics processes to disruptions. However, stability does not mean waiving flexibility. The strength of lean logistics lies precisely in the combination of these two principles.

Each interface means waiting time and extra resources. Therefore, the interface-reduced, end-to-end logistics must be the top planning priority. Frictional losses, organizational coordination processes and data conversions can be avoided. Integrative processes form the basis for lead-time-optimized logistics activities in the company.

Perfect logistics processes require error detection at the point of origin and its immediate and consistent elimination. Perfection in logistics thinking never comes to an end, as it can only be the goal but never the final result due to the high market dynamics. Perfection is always achieved when nothing can be left out without diminishing the customer's benefit. [Klu-2018]

3.2.6 Logistics parties

The increasing demand by a broad range of firms to outsource logistics functions has led to an increasingly developing market for logistics. This demand has resulted in considerable attention and more investigations in the important concept of logistics parties. Logistics outsourcing has attracted the attention of lots of industrialists. As a result, having long-term relationships with logistics parties is already an established practice in today's industry and seems to find its undeniable place in today's growing extent of outsourcing affairs. Third-party logistics (3PL), in particular, receives substantial attention from logistics experts. Furthermore, improved versions of logistics parties, especially fourth parties, are growing with high speed. This chapter will focus on the main logistics parties: 1PL, 2PL, 3PL, 4PL and 5PL.

First-party logistics (1PL)

A 1PL provider is a manufacturing company or individual that can directly handle its shipping and warehousing needs. First party logistics involves just two parties. There is the manufacturer or distributor that ships the goods, and then there is the retailer or customer that receives the goods (the customer). There are no other middlemen involved in the whole process.

Second-party logistics (2PL)

A 2PL is an asset-based carrier that is responsible for the method of transportation. Examples of 2PLs include shipping lines which operate the ships, airlines that operate the planes and hauling companies that operate vehicles. A 2PL is often referred to as a forwarder because their business mainly consists of a means of transportation. [Alv-2020]

Third-party logistics (3PL)

3PL are activities carried out by a logistics service provider performing at least management and execution of transportation and warehousing. In addition, other activities like inventory management, information related activities, value added activities, or supply chain management can be managed by the logistics service provider. 3PLs services can be relatively limited or comprise a fully integrated set of logistics activities. A 3PL can perform the following activities: transportation, warehousing, freight consolidation and distribution, product marking, labeling and packaging, inventory management, traffic management and fleet operations, freight payments and auditing, cross docking, product returns, order management, packaging, reverse logistics, carrier selection, rate negotiation, and logistics information systems.

When a firm decides to outsource their logistics activities, it is crucial to understand the advantages and disadvantages of establishing relationships with 3rd-party logistics providers (3PLs). One of the primary benefits of partnering with a 3PL is the potential to save time and reduce the burden of logistics management. The responsibility of logistics operations can be shared with the 3PL, freeing up the firm's resources to focus on their core competencies. Furthermore, 3PLs can offer expertise and specialized knowledge that can help firms reengineer their distribution networks and achieve economies of scale and scope. This can lead to a reduction in inventory levels, shorter order cycle times, and reduced lead times, ultimately improving efficiency, service, and flexibility. However, it is important to keep in mind the potential risks and drawbacks associated with working with a 3PL, such as loss of control and poor service performance.

When considering outsourcing logistics activities to 3PLs, it is important to understand the potential disadvantages as well. Poor searching and coordination efforts, inadequate information sharing, loss of control, and poor service performance are all risks associated with partnering with a 3PL. In addition, there may be concerns about the expertise of the provider and the quality of their employees. Finally, outsourcing logistics to a 3PL can result in a loss of valuable customer feedback. Nevertheless, with careful consideration and planning, these risks can be minimized, and the benefits of partnering with a 3PL can be substantial.

Fourth-party logistics (4PL)

4PL is advertised as a refinement on the concept of 3PL, a firm that provides outsourced or 3PL services to companies for part or sometimes all of their supply-chain management functions. A 4PL uses a 3PL to supply services to customers, owning only computer systems and intellectual capital. 4PLs play a more consultative role in process management for their customers, so some customers consider 4PLs as advisors or managers, based on their expertise in assembly and supply chain management. [Far-2011]

4PLs offer all the benefits of 3PLs but with additional services. These services may include project management, sourcing and negotiation, logistics strategy and analytics, impartial service advice, and a single point of contact for the client. This level of integration and coordination can result in a more comprehensive and streamlined logistics solution for the firm. The role of the 4PL is to act as a strategic advisor, bringing together multiple service providers and managing the logistics operations on behalf of the client. This allows the client to focus on their core business while relying on the 4PL to manage the logistics activities in an efficient and cost-effective manner. [Rei-2022]

Fifth-party logistics (5PL)

5PL is the discipline that bridges the gaps left between 3PL providers and 4PL providers. Where 4PLs attempt to provide supply-chain solutions with their own optimization software and the capabilities of 3PL resources, 5PLs use the buyer's (first party's) existing technology and infrastructure to optimize the supply chain by transforming into a virtual organization. [Far-2011]

In conclusion, companies should consider which level is most appropriate for them. The nature of the business will generally greatly influence that choice. For example, some might prefer to be closer to the decision-making process, while others might take a hands-off approach and leave the management of the process in expert hands. Outsourcing logistics allows the importer to focus its efforts on other important areas of the business such as promoting sales. However, the most important thing is to carefully examine all the options before deciding on the one that works best.

3.2.7 Logistics future trends

According to a research by Zijn and Klumpp [Zij-2016], in which a large number of articles on logistics and supply-chain management were collected and from which a list of keywords was extracted, the current logistics trend themes were grouped into four main research areas: business process management, competitive advantage, strategic management, and network structure.

The area of business process management deals with management of activities that produce a certain output based on customer demand. It provides methods, techniques, and tools to support the design, management, enactment and analysis of operational business processes. Competitive advantage is a major topic in business practice, including innovative concepts and tools that support organizations to outperform competitors facing major trends. Strategic management describes the identification and implementation of objectives based on assessments of internal and external factors considering efficient resource allocation. The network structure of the supply chain deals with the flow of materials and information from start to end. It also shows the value that has been created due to cooperation with partners.

These four trend categories call for a significant change when designing future-proof supply chains and logistics systems, and technological and social-economic innovations provide adequate tools that may help to address that challenge.

Technological innovations

The following are technological innovations with a high potential to be important and bring great changes to the present and future of logistics.

The design of new lightweight (bio-)materials and their application in a variety of products offer new possibilities to reduce both costs and ecological footprints. Another manifestation of improvement is the continuous development of cleaner engines (e.g., electric, LNG). Since technologies such as 3D-printing and additive manufacturing in general are based on material addition instead of material removal, they have a waste avoidance potential. Smart packaging also may help to reduce volumes and to avoid waste, especially when it comes to biodegradable package materials. Modular product design allows transportation of components instead of products, resulting in a higher package density and allowing customization closer to the end-user. The same holds for 3D printing and micromachining which are a step forward toward mass customization and they also have a profound logistics impact. 3D printing may induce a shift from stock-based to order-based production with shorter lead times and a reduction of stocks when applied in small batch manufacturing.

Automation and robotics

The use of robotics in logistics has already been visible for a long time, for example, in automotive assembly lines or in warehouses and distribution centers (automatic storage and retrieval systems), often consisting of high bay storage racks which are served by fully automated cranes, and equipped with automatic identification such as RFID. Apart from the visible hardware, innovative warehouse management systems help to coordinate and synchronize activities, in close communication with information systems covering suppliers and customers. These types of systems rely on smart sensor and actuator systems, where devices are equipped with sensors that automatically signal when actions have to be initiated. Additionally, materials and machinery themselves are able to communicate with each other and find solutions based on autonomous decision-making using AI-driven algorithms.

Business information systems and new business models

Complex modern supply chains are characterized by the fact that many stakeholders are involved in shaping its ultimate manifestation. These multistakeholder and multidecisionmaker environments require adequate mechanisms to respond to requirements, including distributed architectures, cloud computing solutions, cognitive computing, and agent-based decision support systems. Organizational innovations are key to exploit the potential of advanced information and decision support architectures. The recent focus on data driven models (big data and predictive analytics) marks an important step toward full-blown automated decision architectures. The design and acceptance of decision models based on both horizontal and vertical cooperation in logistics networks, however, is difficult. Although many stakeholders quickly recognize the potential win-win situation arising from collaboration, they find it in general hard to give up decision autonomy.

Circular and sharing economy, servitization

The key idea behind servitization is the realization that both private consumers and industrial asset owners need the functionality of assets and products, rather than the products themselves. The model of a circular economy is based on the idea that products and systems that are disposed of can be restored and reused or disassembled after which components and parts are given a second life in next generation equipment. Sharing economy means to jointly use equipment in a predefined group of people. Those products or systems are either owned by individual group members or remain property of the supplier and can be leased or hired. Such developments may have important consequences for supply chain design, planning and control, because the focus will at least partly switch from delivering products to delivering services.

The physical internet (PI)

The PI is receiving increasing attention from academics and practitioners, who see this new paradigm as a disruptive innovation with the potential to significantly disrupt existing logistics and supply-chain practices.

The PI is defined as a comprehensive and measurable supply-chain framework based on a network of physical components. These components are standardized as well as optimized and exchange information to improve the effectiveness, efficiency, and sustainability of supply chain management operations [Tre-2019]. The PI is a holistic concept that merges numerous relevant areas of logistics and supply-chain management research with the promise of disrupting current logistics and supply-chain management practices. These areas include sustainability, effectiveness and efficiency of global value chains and information flows, as well as horizontal and vertical collaboration. For example, the PI modular containers are world-standard, smart, ecofriendly, and modular aiming to transform the existing transport, handling and storage of cargo containers through smart, sustainable, and seamless automation and human handling.

The main PI objective is to transform the way physical objects are handled, moved, stored, realized, supplied, and used, aiming towards global logistics efficiency and sustainability. The PI aims to organize the transportation of physical goods in a manner similar to the way in which data packages are moved on the digital Internet. By sharing resources, such as vehicles and data, and designing transit centers, which enable seamless interoperability, the transportation of goods will be optimized with regard to cost, speed, efficiency and sustainability. To achieve this optimization, the PI sets common and universally agreed-upon standards and protocols to facilitate horizontal and vertical cooperation between organizations.

3.3 AI implementations and trends in operational logistics

Over the past several years, various industries have heightened their recognition and development of AI and automation in preparation for the fourth industrial revolution. In the past, large-scale enterprises with numerous employees were able to generate significant outputs. However, with the advent of AI and automation, small teams are now capable of producing larger outputs than previously achievable. Many companies have recently integrated these technologies in an effort to increase profitability and enhance competitiveness in their respective markets. The awareness and implementation of AI has been rapidly expanding into both professional and personal spheres since its inception and continues to grow at an exponential rate. [Fos-2020]

Tractica, a market research organization, forecasts that global AI software revenue will increase from $10.1 billion in 2018 to $126 billion by 2025 [Han-2020]. 91% of leading businesses are currently investing in AI. 44% of organizations reduced business costs with AI. [Han-2020; Wat-2022; Cam-2019]

In the supply-chain and logistics industry particularly, AI has proven to be a game-changer. According to a report by McKinsey, by the year 2030, AI will help develop a new-age logistics paradigm. Operational logistics faces many challenges, and AI contributes to overcoming them quickly. Considering the accelerated growth, it is time that the logistics industry advances to a smarter transformation [Int-2022]. Selon McKinsey, implementing AI has helped companies to improve logistics costs by 15%, inventory levels by 35% and service levels by 65%. According to Gartner, more than 75% of commercial supply chain management application providers will deliver AI and data science by 2026. [Ser-2022; Gar-2023]

All companies within a supply chain are interconnected through physical or information flows, and AI tools can enhance or automate these flows. The unique characteristics and behavior of supply chains differ for each business and industry, and therefore a standardized AI solution cannot be created. However, the general benefits that AI-driven technologies can bring to the logistics industry are undeniable. AI can be utilized in various logistics activities, ranging from augmentation (such as connectivity between businesses and data analysis in areas like finance, production, and warehousing) to automation (using machine learning and robotics) [Den-2018]. AI algorithms can establish rules, provide analysis, and make predictions. Additionally, AI can uncover hidden insights within data that may go unnoticed by humans, leading to faster decision-making, reduced cycle-times, and improved operations. In operational logistics, AI is helping to optimize and achieve more accurate capacity planning, increased productivity, higher quality, lower costs, and higher output, all while promoting a safer work environment. [Jac-2022]

The use cases and latest AI-driven technologies in logistics can be divided into categories based on their area of application. These categories include logistics planning, automated warehousing, autonomous devices and the use of AI for analytics and back-office tasks.

3.3.1 Logistics planning

The logistics process requires extensive planning, involving coordination among suppliers, customers, and various internal units within a company. Machine learning solutions can assist in this planning by offering capabilities in scenario analysis and numerical analytics, which are critical components of the planning process. These tools can help to streamline and optimize logistics planning.

The integration of AI technology in the forecasting process allows organizations to utilize real-time data. As a result, AI-based demand forecasting techniques demonstrate a significant reduction in error rates compared to traditional forecasting methods such as ARIMA (autoregressive integrated moving average) and exponential smoothing. By utilizing historical demand patterns, AI can accurately predict future demand for a product. This improved accuracy in demand forecasting allows manufacturers to optimize the number of vehicles dispatched to local warehouses, reducing operational costs and improving manpower planning. Local warehouses can minimize holding costs and companies in competitive environments are less likely to face inventory shortages, which can negatively impact customer satisfaction. Having access to reliable data on future trends and events provides organizations with the opportunity to make necessary changes, including expanding production capacity or acquiring additional supplies. Some predictive models have the ability to learn quickly from massive datasets and produce real-time forecasts, while others can generate short-term predictions to help companies adjust inventory for a specified period. Demand forecasting is crucial for capacity planning, scheduling, and evaluating optimal pricing strategies. By considering market forecasts, a company can determine the ideal price to cover costs, generate a profit margin, and attract the maximum number of customers, maximizing sales figures. AI-driven demand forecasting also helps businesses dynamically update their supply planning parameters to optimize supply chain flow, reducing waste and using fewer resources. [Dil-2020; Nex-2022]

Predictive scheduling is a method utilized in various shipment systems to improve customer satisfaction through the creation of an optimal delivery plan, including scheduling and route optimization. This information is valuable in creating an efficient and timely schedule. By incorporating data from a broad range of sources, a more complete understanding of the situation can be attained, allowing for informed decision making regarding future events. Machine learning models can aid in predictive scheduling through analyzing past shipment information, predicted demand based on forecasting, and any relevant recent events. [Nex-2022]

The task of distributing a large quantity of goods among several warehouses is a complex challenge in supply chain management, as it involves numerous factors and resources that must be considered. The distribution process can be improved through the use of AI, which provides a company with valuable insights into product demand, preferred schedules, potential routing and fleet options, and enables more precise planning in a shorter time frame. AI models used in this scenario operate within predictive analytics and prescriptive scheduling, supported by other specialized solutions. The algorithm should be able to create a plan that considers all relevant interactions. With the ability to learn from historical data, AI-driven solutions can make predictions about future events, and identify patterns in large amounts of data that can be utilized as actionable insights or statistics for running simulations of various scenarios. These models can be optimized for different goals, such as cost-effectiveness, timely deliveries, or reduced warehouse space, depending on the specific needs of the business. The results of this analysis contribute to the resilience of the supply chain. AI technology helps managers make informed business plans and calculate costs to develop a strategy that aligns with their goals. Predictive planning systems can be utilized to optimize decision-making by taking into account factors such as cost, delays, safety, traffic, and weather conditions. [Nex-2022]

3.3.2 Automated warehouse

With growing demand and the seasonal aspect of the workforce needs, finding a skilled workforce that will support warehouse operations is becoming increasingly difficult. Making a small mistake can lead to significant losses, which is why fully automated warehouses are becoming increasingly popular in the logistics industry. Logistics managers are turning to automation by using robots that operate without human involvement. Common applications include automatic storage and retrieval systems (AS/RS), autonomous mobile robots (AMRs), automated guided vehicles (AGVs), and order picking machines that use laser or RFID technology. One of the main technologies used in automated warehousing is AS/RS, which includes storage aisles that are serviced by storage/retrieval machines and stored materials held in a system of storage racks and aisles. The storage/retrieval machines are used to deliver and retrieval materials in and out of inventory in input/output stations (picked and deposit stations). AGVs and AMRs are being explained in the following subsection for autonomous devices and RFID technology has already been set forth in the subsection “Information, control and communication technology” in “3.2.2 Components of logistics systems”. [Han-2019]

AI systems have the potential to revolutionize warehouse operations by enabling the automation of processes previously performed by human workers. These systems are capable of navigating warehouse spaces, identifying required goods in inventory, picking them up and storing them in appropriate locations, or preparing them for delivery, all without human intervention. The manual performance of these tasks presents certain risks and can be time-consuming, but with the integration of AI technology, companies can expect a decrease in costs associated with human labor, including salaries, and a reduction in physical risks associated with human error, fatigue, and the use of heavy equipment. [Nex-2022]

Incorporating AI into warehouse operations can also improve quality control through automated visual inspections. This allows for quick and accurate checks on a large number of products. Poor quality products can result in customer dissatisfaction and loss of business, but with the use of computer vision technology, businesses can detect damage, maintain quality control, and take measures to prevent further damage. Machine vision technology also offers the added benefit of monitoring product condition in a way that is not possible with manual methods. [Dil-2020]

Another business application for machine-learning in warehouses is a predictive maintenance system for machinery that collects real-time data from sensors and analyzes several factors like a component's history, the environment in which it operates, or variables within a part itself to identify patterns in sensor data and determine when a piece of machinery will require service. Predictive maintenance technology can be used in all parts of the supply chain that involve machinery. This technology can efficiently identify the cause and severity of issues and support decision-making by reducing the need for manual intervention. This helps to reduce downtime caused by unplanned repairs and decrease the risk of accidents. By implementing predictive maintenance systems, companies can improve their equipment's reliability, reduce downtime, and increase productivity throughout their supply chain operations. [Nex-2022]

3.3.3 Autonomous devices

AI-enabled autonomous devices work without human interaction with the help of AI. They include examples like self-driving vehicles, drones, and robotics for inbound and outbound logistics. However, this study focuses on the movement and handling of materials and the support operations that occur within a company. A significant part of these sort of activities at a warehouse is automated with the use of various types of equipment like cranes, conveyors, reach stackers, etc. that can easily be operated by an AI system without human intervention, as well as machine vision technology such as Automated Guided Vehicles (AGVs) and Autonomous Mobiles Robots (AMRs).

AGVs are equipped with either electromagnetic or optical guidance systems. These systems have a range of capabilities including human-computer interaction, task execution, positioning and navigation control, power management, obstacle avoidance, and safety alerts. AGVs can be easily integrated into various environments, including production lines, assembly lines, and conveyor lines. Different functions can be achieved based on specific requirements and combinations. AGVs use a modular design and can operate as standalone systems when integrated with production and scheduling systems. Their increasing use in operational logistics is due to benefits such as reduced transportation times, increased safety, reliability, flexibility in adapting to material flow, reduced labor, and increased productivity. [Li-2018]

AMRs are equipped with advanced sensors, AI software, and a digital layout of their surroundings. They work in conjunction with a warehouse control system (WCS) and a warehouse management system (WMS) in a storage environment. With the help of these software applications, AMRs are able to determine optimal routes and avoid obstacles while handling goods. For example, they can differentiate between a permanent obstacle like a rack and a temporary obstacle like a forklift and react accordingly. The integration of AMRs with other systems in the installation will be improved with the increasing use of 5G technology. The robots provide valuable data on logistics operations and are key to improving productivity, reducing costs, and enhancing safety in shipping and warehouse operations by saving time and reducing risks. [Mec-2021]

3.3.4 Analytics and automation for back-office operations

Pricing for logistics and transportation services is subject to change and it's important for both service providers and buyers to have accurate pricing. Prices for a route or service depend on factors such as demand, time, weather, and geopolitical issues. AI solutions can not only automatically adjust prices but also provide insights into the reasons for changes, such as changes in demand, delays, disruptions, or overcapacity. This information can assist managers in making decisions about future business plans and pricing. Dynamic pricing of logistics services is an area where AI can have a major impact. In order to implement a dynamic pricing solution, a company needs data on performance, both historical and recent, as well as information on seasonal trends, demand for goods, and competitors' prices. By combining this data, an AI system can continually refine its pricing estimates to provide the customer with the best offer. The AI system can even take into account specific customer preferences, such as seasonality or location, by finding patterns in the data.

The use of AI-powered route optimization for internal transportation devices like AGVs and AMRs is a popular trend in the material handling and warehousing sector. Optimal route identification involves finding the most efficient route within a company's facilities to meet delivery deadlines and follow certain rules, leading to faster travel times, better use of vehicles, and reduced operating expenses. [Nex-2022]

The use of document automation technology and innovative solutions like Natural Language Processing (NLP) and Robotic Process Automation (RPA) can greatly enhance back-office operations in the logistics industry, saving time, reducing errors, and increasing efficiency. Documents such as invoices, bills of lading, and rate sheets facilitate communication among buyers, suppliers, and logistics providers. The use of document automation technology can streamline the handling of these documents by automating data entry, correcting errors, and simplifying document handling processes.

NLP is a subfield of computer science and AI concerned with enabling computers to understand, interpret, and generate human language. Logistics industry solution providers are incorporating NLP into their solutions to make use of the large amounts of written communication and unstructured text data found in companies. NLP can quickly extract crucial information to improve back-office automation for a business. Handling invoices, bills of lading, customs declarations, purchase orders, and other necessary documents in the logistics industry is a time-consuming and labor-intensive task that can result in human error and wasted resources. With NLP, document processing can be automated, reducing errors and saving time. NLP solutions can assist logistics providers with various back-office processes, such as generating documents, sending automatic alerts, performing automated data extraction (e.g., searching for a particular word or a combination of words in the text), and correlating information with other documents or images. [Nex-2022]

Robotic Process Automation (RPA) is a technology that allows software robots to automate routine and repetitive tasks typically performed by humans. RPA works by automating manual, time-consuming, and error-prone processes using software bots, thus reducing the need for manual intervention and increasing efficiency. The software bots interact with applications in the same way that a human user would, using the user interface and generating the same results. RPA technology can automate business processes that need human interaction, such as finance and accounting, data entry, document handling, scheduling and transportation management, workforce assignment, and package tracking in the warehouse. RPA solutions can automatically produce reports, analyze the data, and send them to the appropriate parties via email. This technology allows companies to make more efficient use of their resources by relieving employees from repetitive tasks and allowing them to concentrate on tasks with higher value. [Nex-2022]

3.4 Challenges related to AI implementations in operational logistics

The field of AI has made great progress in a short amount of time, however, there are still challenges that need to be overcome to fully utilize its potential. The implementation of AI in logistics management is faced with several difficulties, including the need for collaboration between multiple parties, varying data sources, resistance to AI adoption, difficulties with change management, and the lack of a governing framework for AI. The top leadership in organizations may embrace the potential of AI to give them a competitive edge, but middle management remains uncertain of its benefits. Those organizations that have successfully applied AI have two key elements contributing to their success: a strong commitment to data-driven decision making, leading to the development of a data-centric culture, and sustained investment in AI training and talent by the leadership. This chapter takes a comprehensive approach to examining the challenges firms present to successful AI implementation in logistics operations, which have been divided into 10 different types of barriers as shown in the overview in Figure 3-6. [Shr-2022]

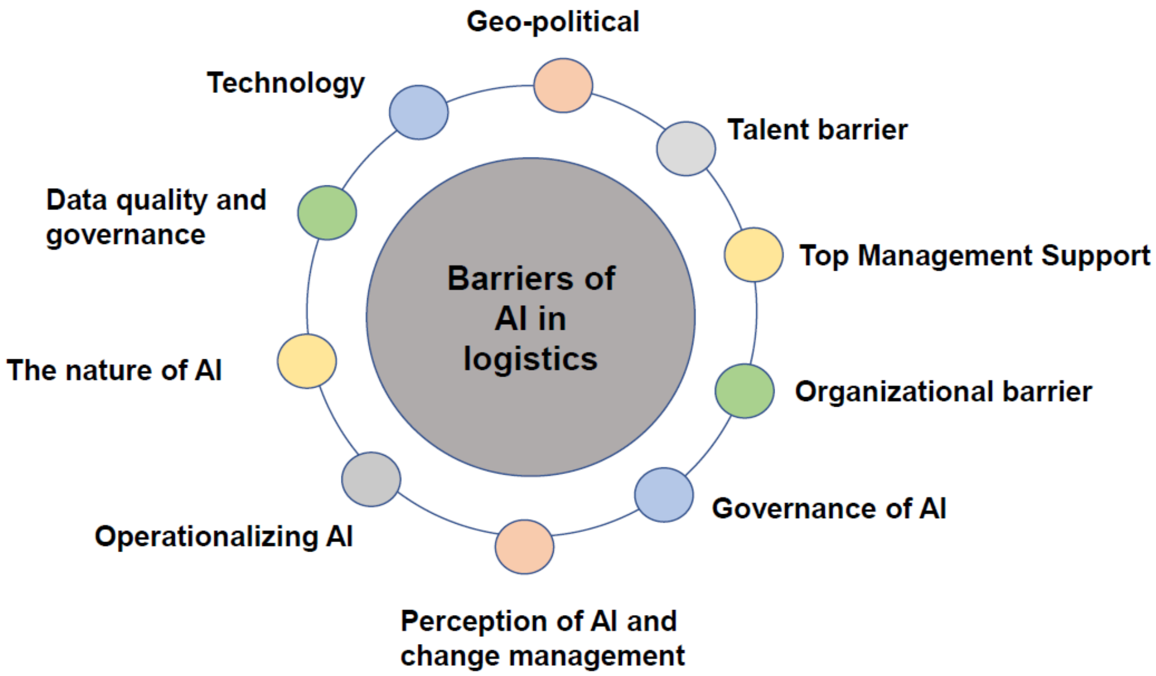

Figure 3-6: Overview of barriers of AI in logistics

Top management support

The involvement of a company's top management is crucial in every aspect of AI implementation. They provide support during the research and development phase and give approval to scale AI initiatives within the company. In an AI-focused company, leaders are willing to take risks and allow experimentation to gather feedback. They are also active proponents of AI, continually adapting their views and promoting the technology in both internal and external meetings. Their level of understanding of AI will also determine the company's strategy for building or outsourcing AI solutions.

However, it's not just the top management's support that matters, it's also important for leaders across different parts of the supply chain to understand the benefits of AI and be in alignment with its implementation. They don't have to have a deep technical understanding of AI, but they should believe in using data to make decisions rather than relying on intuition. A lack of agreement on the value of AI can create significant obstacles and have a cascading impact on AI initiatives. For AI to be successful, the leadership of all supply chain actors must be on the same page, committed to sharing resources and information and focused on the larger benefits of AI, and they must also agree on the potential use cases where AI can be most effective. [Shr-2022]

The nature of AI

AI models often have complex structures and are difficult for humans to understand, referred to as the "black-box" nature of AI. In logistics management, this black-box nature presents a major challenge as human decision-makers are still accountable for many decisions, and it is not fair to expect them to accept AI recommendations without a clear understanding of how they were made. Furthermore, a lack of understanding of the role of feedback loops and experimentation in AI performance is also an issue in logistics management. In recommendation systems, for example, the flow of user activity data is crucial for the AI agent to continually learn and adapt, but in the supply chain, too much information flow can lead to the bullwhip effect.

The lifecycle of AI projects is longer than traditional software and requires constant monitoring and validation for relevance. This long-term and evolving nature of AI initiatives means management must be committed and have dedicated resources available to prevent bottlenecks. In inter-organizational initiatives, there must be strategic alignment and resource commitment to ensure success. [Shr-2022]

Organizational barrier

Organizational challenges in implementing AI can be divided into six main categories. Firstly, the large size and complexity of a company can make it difficult to adopt AI. Secondly, some workers may resist the change brought by AI due to the need for reskilling and adapting to new ways of working. Thirdly, a lack of understanding of AI across the organization can be an issue. Fourthly, different priorities and goals within the business and between organizations can cause confusion and conflict. Fifthly, misaligned goals and objectives can also create barriers to AI implementation. Lastly, the high cost of AI initiatives can be a hindrance, as not all stakeholders may be willing to invest in AI solutions that have long-term benefits and uncertain ROI. These challenges can lead to de-prioritization, delays, or even abandonment of AI projects, making it difficult for AI to succeed in the logistics industry. [Shr-2022]

Data quality and governance barriers

The quality of big data is a critical factor in the adoption of AI. Poor quality data, such as errors, missing values, and inaccurate information, limit the accuracy of AI models. However, having large amounts of high-quality data is often difficult to obtain in real-world situations. To overcome this challenge, all participants in the supply chain must work together to establish a unified data platform with consistent definitions, clear responsibilities for data collection, and dedicated resources for maintaining data quality. Good data governance is also necessary to ensure that data is used in a safe and legal manner. [Shr-2022]

Technology barriers

Developing AI algorithms involves creating a hypothesis for the environment in which the AI agent will operate. This process involves training the agent through multiple iterations with various algorithms, such as tree-based or neural networks, and adjusting the architecture and hyperparameters to increase accuracy. The development of AI solutions requires not only specialized infrastructure but also a significant computing budget. Once the agent is trained and tested, it must then be scaled, leading to increased computational costs. In the case of logistics algorithms, they must also be able to handle different types of IoT data from various sensors, requiring system compatibility to process this information. [Shr-2022]

Perception of AI and change management barriers

One major obstacle in the implementation of AI in logistics is the lack of consistency and uniformity in measuring its performance. Different departments within the same organization may have varying interpretations of an AI algorithm's effectiveness, due to factors such as unconscious biases or limited scope of the AI project. The unrealistic expectation that AI should outperform human capabilities also contributes to negative perceptions and skepticism towards its implementation. However, poor performance or missed situations by AI should be viewed as opportunities for improvement, as the AI system learns from data and feedback. A lack of patience, uncertainty about the future with AI, and misunderstandings about performance metrics all contribute to resistance towards AI adoption.

In addition, miscommunication between organizations about AI initiatives can lead to competition rather than collaboration, which is essential for effective logistics management. A change management strategy and a top-down approach towards AI implementation are necessary to overcome these roadblocks and improve communication and collaboration across the supply chain. [Shr-2022]

Barriers during operationalizing AI

The differences in the IT systems used by different organizations in the supply chain can create difficulties in integrating AI at an inter-organizational level. This is because not every player in the supply chain is equally advanced in their digital transformation journey, and even if they are, there is a lack of consistency in technology standards that can cause misalignment between IT systems. The implementation of AI often requires integration with in-house data platforms and training platforms to produce output that can be consumed by downstream execution systems. However, many supply chain players use legacy IT systems or third-party software, making integration challenging. This requires building a consumption layer to seamlessly integrate the AI output, which requires significant engineering resources and collaboration between the science team and business function engineering teams, making the integration of AI systems with existing operational logistics systems a complex and time-consuming process. [Shr-2022]

Governance of AI

The fast pace of AI technology advancements has outstripped the development of governing standards and regulations. This lack of clear guidelines presents a major challenge for AI implementation, particularly in inter-organization supply chains. To address this, supply chain partners must work together to establish accountability of algorithms, ethical concerns surrounding AI use, and data-related issues. This requires agreement on the problems being solved with AI, who is responsible in the event of AI system failure, and principles for using AI ethically. A lack of agreement on these key areas creates resistance among organizations to invest in AI solutions for logistics functions, even though it offers significant benefits. Self-governance and responsible AI use are essential for successful AI implementation in logistics. [Shr-2022]

Talent barriers

The lack of access to skilled AI professionals is a major challenge facing many industries. The shortage of AI talent and difficulty in hiring is one of the top obstacles to AI adoption within organizations. While universities are increasing their AI-related programs to train future graduates, there is still a significant shortage of experienced AI professionals. Real-world AI projects often require a deep understanding of the relevant business domain, which is often lacking in recent graduates. This shortage of skilled AI workers has led to high demand for data scientists, driving up costs for companies. To effectively compete for AI talent, organizations need to create separate job categories for AI with more attractive compensation packages. [Shr-2022]

Geo-political barriers

Geopolitical events can be devastating for supply chain management and can also negatively impact AI systems used in logistics. Tensions in the world can add confusion to the data used for AI training and can cause a period of unpredictability for the future. These events increase uncertainty and can create delayed disruptions in the data. AI can help companies deal with these challenges by creating simulations and providing optimal solutions, but it can also suffer if the AI models are not updated correctly or if the geopolitical events are not accurately labeled in the data sets. [Shr-2022]

4 Analysis & Discussion

Logistics is a critical component of any business that aims to achieve operational efficiency and cost-effectiveness. Operational logistics systems involve the management of the flow of goods and services from the point of origin to the point of consumption, being the internal logistics the main focus of this study. This process involves several stages, including transportation, warehousing, inventory management, and order fulfillment. Over the years, advances in technology have revolutionized logistics, leading to the development of sophisticated systems that can automate and streamline various processes. AI has already made significant contributions to various industries, and the logistics sector is no exception. The integration of AI into operational logistics systems has the potential to improve operational efficiency, reduce costs, and enhance customer satisfaction.

However, the implementation of AI in logistics systems is still in its early stages, and there are different AI applications that can be used in operational logistics. As such, there is a need to evaluate these AI applications to determine their effectiveness in enhancing operational logistics systems. This evaluation will involve assessing the different AI applications' ability to streamline processes, reduce errors, optimize inventory management, and enhance customer satisfaction.

Taking the previous theoretical overview on operational and internal logistics, on AI principles and on available AI implementations in operational logistics into account, this chapter aims to analyze and evaluate different AI applications for operational logistics systems. The chapter will provide a comprehensive analysis of the different necessary criteria to effectively evaluate an AI-driven logistics system.

4.1 Criteria for evaluating AI applications in operational logistics

With the rise of AI technology, the logistics industry has seen a significant improvement in efficiency and performance. As a result, there is a growing interest in evaluating different AI applications for operational logistics systems. The evaluation criteria for logistics systems play a vital role in determining the effectiveness of these applications.

In this chapter, we will explore the evaluation criteria that are critical in determining the success of the application of AI in internal logistics systems. The success of AI-driven applications in logistics relies heavily on how well they meet the key evaluation criteria, including accuracy, speed, scalability, reliability, cost-effectiveness, user-friendliness, ethical and legal compliance, security, and integration. Figure 4-1 shows an overview of these criteria.

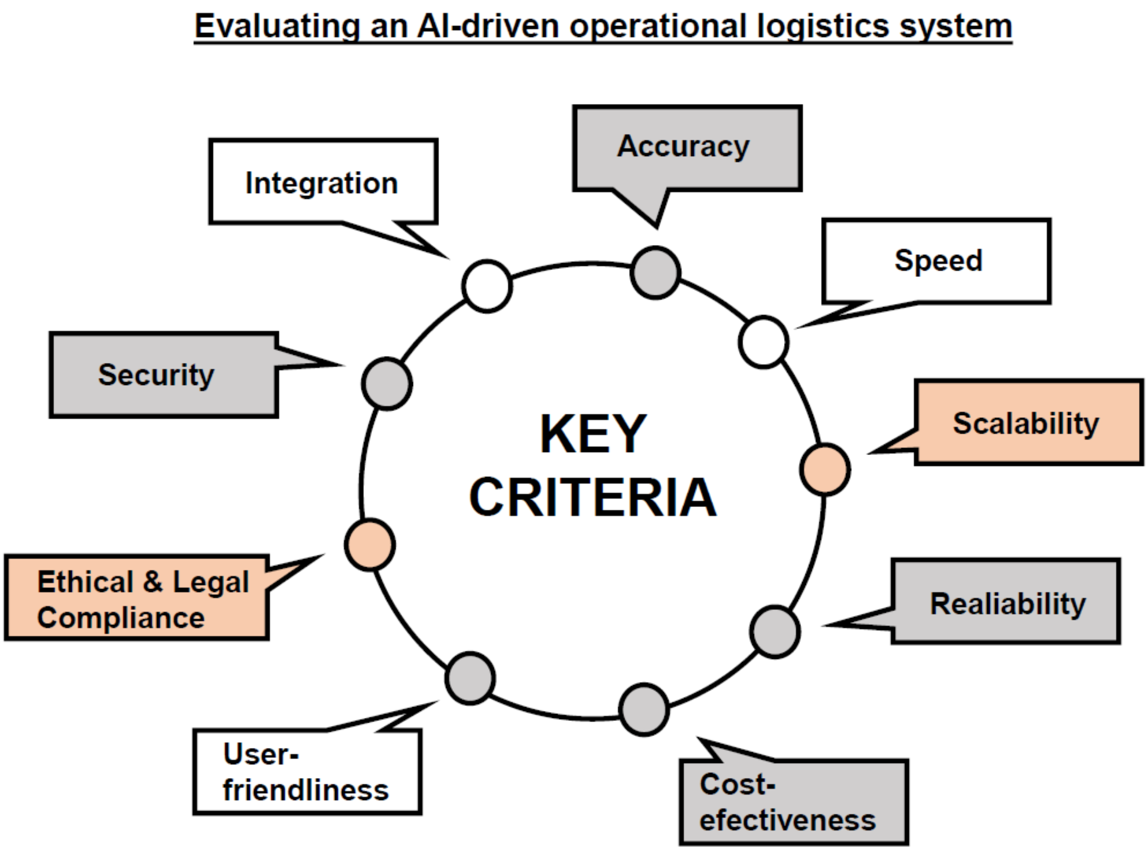

Figure 4-1: Overview of the key criteria for evaluating AI logistics systems

The selection of evaluation criteria plays a critical role in determining the success of applying AI in internal logistics systems. There are various reasons for this. To begin with, accuracy is essential for the logistics industry as it requires precise tracking and tracing of goods throughout the supply chain. Inaccuracies can lead to serious financial losses. Similarly, speed is crucial as any delays in logistics processes can also result in significant financial losses. Furthermore, logistics processes are often complex, and scalability is necessary to provide large-scale solutions that can adapt to changing demands.

Moreover, reliability is a crucial criterion for logistics operations, which must be consistently available and functioning. Logistics systems must also be robust enough to handle unexpected situations such as system failures or disruptions in the supply chain. Cost-effectiveness is selected as one of the main evaluation criteria since logistics companies are constantly looking for optimizing costs and remaining competitive in the industry.

Additionally, user-friendliness is crucial as logistics workers must be able to understand and use the systems efficiently. Ethical and legal compliance is also essential, as logistics companies must comply with regulations and ensure ethical practices. Security is vital as logistics systems contain sensitive information, and any breach can result in significant damage. Finally, integration is important because logistics systems often need to integrate with other systems and applications to operate effectively.

Overall, understanding the importance of the chosen evaluation criteria is essential in implementing successful AI solutions in logistics systems. These criteria are essential in determining the effectiveness and efficiency of AI-powered logistics systems.

Next, we will discuss each criterion in detail and explore how they impact the effectiveness of AI-powered logistics systems.

Accuracy

One of the most critical criteria for evaluating logistics systems is accuracy. In logistics, accuracy refers to the percentage of correct predictions or decisions made by the AI system in relation to the total number of predictions made [Bre-2022]. The accuracy of AI applications can significantly impact the efficiency of a logistics operation. High accuracy is essential for reducing errors, improving customer satisfaction, and minimizing costs. By ensuring high levels of accuracy in different areas of logistics, companies can gain a competitive advantage in the market, since information about future demand is a basis for the firm's capacity planning, workforce scheduling, inventory control, new-product development, and promotional campaigns. Evaluation of accuracy involves verifying the accuracy of predictions made by the system against actual outcomes.

One area where accuracy is crucial is inventory management, since accurate inventory management ensures that the right products are available when customers need them. AI-powered systems can analyze historical data to predict future demand and ensure that the right amount of inventory is available at the right time. [Min-2009]

Another area where accuracy is essential is in predictive maintenance. Accurate predictive maintenance is critical for keeping equipment in good working order, optimizing time management and reducing costs related to unplanned downtime. AI can analyze sensor data from equipment to identify when maintenance is needed and schedule it before a breakdown occurs, for example. [Nex-2022]

Efficiency route optimization in internal logistics in warehouse and material handling is a crucial aspect that demands accuracy. It plays a significant role in decreasing the expenses incurred during transportation and material handling and enhancing the delivery time. AI-based systems can thoroughly examine various parameters, including location of products, the size of the inventory, the type of material handling equipment, and the available resources to determine the most efficient routes for each transportation task.

Accuracy is of utmost importance in detecting fraudulent activity and misinformation in supply chains with machine learning models. A variety of fraud in Supply Chains may be detected either in physical parts or in cyber data. Accurate fraud detection can help prevent financial losses. AI-based systems can analyze transactions and identify patterns that may indicate fraudulent activity. This proactive approach enables logistics companies to take necessary actions to mitigate potential losses. [Sei-2022]

Additionally, accuracy plays a significant role in maintaining product quality. Ensuring products meet customer expectations is essential in quality control. AI-powered systems can scrutinize various data, including images, to identify defects and ensure that only high-quality products are delivered to customers. This approach can help maintain customer satisfaction and brand loyalty. [Dil-2020]

Speed

In today's fast-paced world, speed is a crucial factor in logistics operations. With the advent of AI-powered logistics systems, processing massive amounts of data and providing real-time insights and decisions have become even more important. The speed of an AI application is measured based on its ability to process data, generate insights, and make decisions quickly. The faster the system, the more efficient the logistics operations will be.

One significant benefit of speed in logistics is the ability to make faster decisions. For example, real-time data processing can help warehouse managers to quickly track inventory levels and respond to changes in demand. This allows them to optimize inventory levels, reduce costs, and avoid stockouts, all of which ultimately leads to improved customer satisfaction. Similarly, real-time insights can help fleet managers to optimize routes, adjust delivery schedules, and reduce transportation costs.

Speed also helps in the early detection and prevention of issues. For example, predictive maintenance is an AI-powered system that monitors equipment and identifies potential problems before they occur. By detecting and addressing maintenance issues in real-time, businesses can avoid costly downtime, improve operational efficiency, and reduce maintenance costs.

Real-time data processing and analysis can also improve supply chain visibility, enabling logistics managers to track shipments, monitor delivery times, and identify potential bottlenecks in the supply chain. With greater visibility, businesses can reduce lead times, minimize stock levels, and improve the accuracy of delivery times. This is particularly important in industries with high demand volatility and seasonal fluctuations. Real-time data from sensors, cameras, and other sources processed by AI-powered systems can also determine the best routes for forklifts and other material handling equipment. These systems can quickly analyze real-time data and adjust routes based on changing conditions, such as unexpected obstructions or changes in inventory levels.

In conclusion, the ability to process massive amounts of data and provide real-time insights and decisions is critical for logistics operations. Evaluating the speed of AI-powered logistics systems involves measuring the processing time of the system and comparing it to the desired response time. This evaluation can help identify areas where the system may be slow and needs improvement. The goal is to ensure that the system can process data and make decisions quickly enough to keep up with the pace of logistics operations. Speed is not only important for enhancing efficiency and reducing costs, but it also helps in improving customer satisfaction and maintaining a competitive edge in the market. Therefore, logistics companies need to invest in AI-powered systems that can provide real-time insights and decision-making capabilities to stay ahead in the game. [Jac-2023; Owc-2021]

Scalability

AI scalability is the ability of AI algorithms, data, models, and infrastructure to operate at the size, speed, and complexity required for the mission and it is a critical factor to consider when evaluating internal and AI-based operational logistics systems for several reasons. Firstly, companies that are experiencing growth need to be able to expand their operations without experiencing any significant disruptions or limitations. As a result, a scalable logistics system can accommodate the company's growth and increase in demand, allowing it to continue operating efficiently even under increased loads.

Secondly, the use of AI in logistics operations is becoming more prevalent, and as AI applications generate more data, the ability to handle large volumes of data becomes essential. A scalable logistics system can handle the ever-increasing volume of data generated by AI applications without compromising performance, thus ensuring that the logistics operation remains efficient and effective.

Furthermore, scalability is vital in ensuring that logistics systems can handle increased numbers of users. As a company grows, it may require more employees or customers to access the logistics system, and a scalable system can accommodate these users without compromising performance. Therefore, evaluating a logistics system's scalability involves testing the system's ability to handle increased user loads while maintaining optimal performance levels.

In addition to accommodating growth and increased user loads, a scalable logistics system can also handle unexpected spikes in demand. For example, during peak seasons, such as holidays or special events, logistics operations may experience a surge in demand. A scalable system can quickly and efficiently handle the increased demand without impacting the overall performance of the logistics operation.

In conclusion, scalability is an important criterion for evaluating internal and AI-based operational logistics systems. A scalable logistics system can handle increased volumes of data and users while maintaining optimal performance levels, allowing the logistics operation to continue operating efficiently and effectively. As logistics operations continue to evolve and grow, scalability will become an increasingly critical factor in evaluating logistics systems. [Bar-2021]

Reliability

Reliability is a critical factor for evaluating internal and AI-based operational logistics systems. In the logistics industry, reliability means the ability of a system to perform consistently over time without any failures or errors. It is a crucial factor because any disruptions in the logistics operations can lead to delays, damaged goods, loss of revenue, and even lost customers. For example, in warehouse operations, reliability is essential to ensure that inventory is accurately tracked and shipments are prepared and shipped on time. Therefore, it is essential to ensure that logistics systems are reliable to keep operations running smoothly and customers satisfied.

One significant advantage of AI-based logistics systems is their ability to continuously analyze and learn from data, leading to improved reliability over time. For instance, AI algorithms can analyze historical data to identify patterns and predict future outcomes, such as demand fluctuations or supply chain disruptions. This enables logistics companies to proactively take actions to prevent issues before they occur.

Moreover, reliability can be evaluated based on the system's uptime and the frequency of errors or failures. Uptime refers to the period during which the system is available and operational. High uptime is crucial in logistics, as any downtime can lead to delayed shipments, lost revenue, and dissatisfied customers. Therefore, it is essential to have a reliable backup system in place to minimize the impact of downtime.

Another aspect of reliability is the frequency of errors or failures. Even the most reliable logistics systems can experience occasional errors or failures. However, the frequency and severity of these errors can significantly affect the system's overall reliability. Therefore, it is essential to monitor and track errors to identify patterns and improve the system's overall reliability.

In conclusion, reliability is a crucial criterion for evaluating logistics systems, including internal and AI-based operational logistics systems. It is essential to ensure that logistics operations run smoothly and customers receive their orders on time. Reliability can be measured based on uptime, frequency of errors or failures, and the ability of the system to continuously learn and improve over time. [Bro-2021]

Cost-effectiveness

One significant advantage of AI-based logistics systems is their ability to reduce costs by minimizing errors and reducing the need for manual labor. For example, an AI-based inventory management system can help reduce inventory carrying costs by optimizing inventory levels based on demand patterns, thus minimizing the need to overstock or understock items. Similarly, an AI-based route optimization system can help reduce transportation costs by identifying the most efficient and cost-effective routes for material handling devices.

Another critical aspect of cost-effectiveness in AI-based logistics systems is increased efficiency. By automating time-consuming tasks and optimizing operations, these systems can help logistics companies save time and resources. For example, an AI-based warehouse management system can help streamline the process of receiving, storing, and dispatching goods, reducing the time and labor required to manage the warehouse. Furthermore, cost-effectiveness is essential for ensuring that logistics operations remain competitive and profitable. With increased competition in the market, logistics companies need to optimize their operations continuously to remain profitable. AI-based logistics systems can help achieve this by identifying opportunities for cost reduction, improving efficiency, and increasing productivity.

To evaluate the cost-effectiveness of an AI-based logistics system, it is necessary to compare the costs of implementing and operating the system with the benefits it provides. The benefits can include reduced costs, increased efficiency, improved accuracy, and higher productivity. A positive return on investment is achieved when the benefits outweigh the costs.

In conclusion, cost-effectiveness is a crucial criterion for evaluating AI-based operational logistics systems. By reducing costs, increasing efficiency, and generating a positive return on investment, cost-effective systems can help logistics companies remain competitive and profitable in today's market. Therefore, it is essential for logistics managers to evaluate the cost-effectiveness of AI-based logistics systems before making significant investments in these systems. [Jac-2023; Owc-2021]

User-friendliness

User-friendliness is particularly important for evaluating AI-based operational logistics systems for several reasons. Firstly, logistics operations involve a wide range of stakeholders, including warehouse personnel, truck drivers, dispatchers, and customers. Each of these stakeholders has different roles and responsibilities in the logistics process, and they need to be able to interact with the system easily and efficiently to perform their tasks. A user-friendly logistics system can provide a more seamless experience for stakeholders, enabling them to perform their tasks quickly and easily. For example, a warehouse worker should be able to use an AI-based system to quickly locate inventory items, manage orders, and track shipments. A truck driver should be able to use a logistics system to optimize their route, avoid traffic congestion, and communicate with dispatchers easily.

Moreover, user-friendly logistics systems can reduce the potential for errors and mistakes and improve the overall productivity and efficiency of logistics operations. When users are forced to navigate a complex or confusing system, they are more likely to make errors that could lead to delays, errors in shipment, or other logistical issues. However, well-designed logistics system with intuitive features and user-friendly interface can minimize the potential for errors and reduce the time and effort required to complete tasks. For instance, an AI-based system that can automate tasks such as inventory management, order tracking, and shipment tracking can reduce the workload on human operators and free them up to focus on more complex tasks that require human expertise.

Ethical and Legal Compliance

Ethical and legal compliance is an essential criterion for evaluating logistics systems. AI applications must comply with ethical and legal standards to ensure that logistics operations are conducted fairly and legally. The ethical and legal compliance of a logistics system can be evaluated based on its adherence to ethical principles and legal regulations. Evaluation of ethical and legal compliance involves examining the system's adherence to ethical principles and legal regulations and is crucial, since these systems can have significant impacts on individuals, communities, and the environment. Ensuring that these systems operate in an ethical and legally compliant manner is essential to prevent harm or negative consequences, establish trust and credibility among stakeholders, and avoid legal and financial penalties.

One key example of ethical and legal compliance is fair treatment of employees. AI systems can be used to manage and optimize logistics operations, such as scheduling, routing, and warehouse management. It is essential that these systems do not lead to unfair treatment of employees, such as by assigning them unreasonable workloads or denying them breaks.

Another example is data privacy and security. AI-based logistics systems rely on data to operate effectively, and it is critical that these systems comply with data privacy and security regulations to prevent unauthorized access or misuse of sensitive information.

Environmental sustainability is also an important aspect of ethical and legal compliance in logistics systems. Logistics operations can have significant environmental impacts, including greenhouse gas emissions and waste generation. Ethical and legally compliant logistics systems should prioritize sustainability, such as by using eco-friendly transportation methods or reducing packaging waste.

Lastly, non-discrimination is another key example of ethical and legal compliance in general. These systems must not discriminate against individuals based on their race, gender, age, or other protected characteristics. [Eur-2021]

Security

Security is a critical aspect of evaluating AI-based operational logistics systems as the reliance on technology in logistics operations continues to grow. The integration of AI applications in logistics systems brings about many benefits. However, these systems are vulnerable to cyber-attacks and data breaches, which can cause significant disruptions to logistics operations.

AI-based operational logistics systems generate vast amounts of data, including sensitive information such as customer data, inventory data, and financial data. Hackers can use this information to steal confidential information, disrupt operations, or even demand ransom. Therefore, it is crucial to ensure that logistics systems are secure and protected from such threats. Artificial intelligence can offer logistics security services that oversee a complicated network of users and devices for any suspicious behavior, strange occurrences, or deviations in activity patterns. This is accomplished through a range of algorithms that are specifically designed to identify abnormalities and can notify relevant parties about an event even if the data does not show any clear indication of concern. This approach allows us to address potential threats before they escalate into actual threats.

To evaluate the security of an AI-based operational logistics system, several factors need to be considered. These include data protection, authentication and authorization mechanisms, access controls, and secure communication protocols. The system's ability to detect and respond to security incidents, such as data breaches or cyber-attacks, is essential. [Nex-2022]

Integration

Integration is a critical aspect of evaluating AI-based operational logistics systems as the success of logistics operations largely depends on how well different systems and technologies work together. AI applications must be integrated seamlessly with existing systems to ensure that logistics operations run smoothly. Integration enables different systems to communicate and share information, allowing logistics companies to streamline their operations and make better decisions. The integration of AI applications with existing systems such as warehouse management systems (WMS) and enterprise resource planning (ERP) systems can improve the speed, accuracy, and efficiency of logistics operations.

For example, an AI-based logistics system that can integrate with a WMS can help logistics companies optimize their inventory management, reduce lead times, and increase productivity. It can also help identifying potential equipment failures before they occur, enabling them to schedule repairs or replacements proactively. This can prevent costly downtime, improve equipment lifespan, and ensure that goods are delivered on time.

Evaluation of integration involves testing the system's ability to connect with other systems and exchange data. The system's ability to seamlessly integrate with existing systems is essential for ensuring that logistics operations are conducted efficiently and effectively. Integration testing should include data exchange testing, application program interface (API) testing, and testing of system interfaces to ensure that all systems can communicate and share information effectively. [Gee-2022; Ana-2021]

Although there are several criteria that could be considered for evaluating AI-driven operational logistics systems, I chose to focus on the selected ones as the key criteria for my study. However, there were a few other criteria that I considered but eventually did not include in my research.

One such criterion is the adaptability of the system to changing market and business conditions. While this is an important factor for any operational logistics system, I believed that it was closely related to scalability and reliability, which I already included in my research. Another criterion that I did not include was sustainability. While the environmental impact of the system is an important issue in logistics, I did not include it in my research as it is not directly related to the performance of AI-driven operational logistics systems.

Overall, I believe that the selected key criteria provide a comprehensive and well-rounded framework for evaluating AI-driven operational logistics systems, and they will enable me to develop an evaluating system for logistics departments implementing AI.

4.2 Evaluation system

An evaluation model for an AI application in an internal logistics system should be designed to assess the effectiveness and efficiency of the AI application in meeting the objectives of the logistics system and satisfying the key criteria for the evaluation. Here are some key steps to designing such an evaluation system:

4.2.1 Defining the objectives

When designing an evaluation model for an AI application in an internal logistics system, the first step is to clearly define the objectives of the logistics system. These objectives should be specific, measurable, achievable, relevant, and time-bound (SMART). Examples of logistics system objectives could include reducing delivery times by 20%, minimizing inventory levels by 10%, optimizing routes to save 15% on transportation costs, and increasing customer satisfaction ratings by 5%. Defining clear objectives helps to provide focus and direction for the evaluation process and ensures that the AI application is aligned with the business goals of the logistics system.

It's important to consider the key evaluation criteria when defining the objectives, as they can help identify areas of the logistics system that are most critical to the success of the AI application.

For example, reducing delivery times could be a primary objective for a logistics system, but it's important to consider how accuracy, reliability, and scalability will affect the system's performance in achieving that objective. Similarly, minimizing inventory levels could be another objective, but it's important to consider the trade-offs between inventory and delivery times, as well as how user-friendliness and cost-effectiveness will impact the system's performance.

By considering the key evaluation criteria when defining the objectives, organizations can ensure that the objectives are realistic, achievable, and aligned with the organization's goals. Below, some of the specific goals for every criterion that can help guide the evaluation and improvement of the system are stated:

Accuracy

In an AI-driven logistics system, the criterion of accuracy is of big importance. It is imperative to ensure that all processes are executed with precision to avoid any errors or inaccuracies. There are several goals that can be set to achieve accuracy in an AI-driven logistics system.

One goal might be to increase the percentage of orders that are fulfilled correctly on the first attempt, which enhances customer satisfaction and reduces the workload of the logistics system. Another important objective is to minimize misdeliveries or incorrect items shipped to customers, which can damage the reputation and loyalty of customers. To avoid inaccurate orders and inconvenience to customers, reducing the frequency of stockouts or overstocking of inventory is necessary. Improving the accuracy of demand forecasting is also crucial to maintain optimal inventory levels and ensure the availability of products when required. Minimizing order cancellations or returns due to inaccurate order fulfillment is another essential objective, since it not only results in financial losses but also causes inconvenience to customers. Efficient utilization of resources and cost savings can be achieved by improving the precision of inventory management. Another objective is to increase the accuracy of automated picking and packing systems, ensuring that orders are processed accurately and delivered on time. To ensure the smooth and efficient operation of the logistics system, minimizing the number of delays or disruptions in the supply chain due to inaccurate forecasting or planning is necessary. Lastly, accurate billing and invoicing processes lead to timely payment and customer satisfaction, making it crucial to improve their accuracy.

Speed

Speed is a crucial criterion that directly impacts the efficiency and effectiveness of the entire supply chain. To optimize speed, there are a variety of goals that can be pursued.

For example, increasing the number of orders processed and shipped per hour, day, week, or month can improve overall throughput. Additionally, minimizing the time between order placement and order fulfillment can enhance customer satisfaction. Another goal related to speed is reducing the time it takes to pick and pack orders. This can significantly increase efficiency in the warehouse, ultimately leading to faster delivery times. Moreover, improving the speed of data processing and analysis is also a critical objective as it enables real-time visibility into the supply chain. Reducing the time it takes to resolve issues or disputes related to orders, billing, or inventory management is also a crucial goal in a logistics system driven by AI. Additionally, increasing the speed of decision-making by providing timely insights and recommendations to logistics managers can lead to greater efficiency. To respond to changing market conditions or unexpected events that impact the supply chain, it is also essential to reduce the time it takes to react. Finally, improving the speed and accuracy of automated decision-making processes can significantly increase efficiency and reduce delays.

Scalability

Scalability is an important criterion to ensure that the AI-based system can handle increasing volumes of orders and support business growth without sacrificing performance or accuracy. There are several goals that can be stated to achieve scalability.

Firstly, it is important to increase the capacity of the logistics system to handle higher volumes of orders, without causing any performance issues or inaccuracies in order processing. Furthermore, improving the ability of the system to handle a larger number of goods or product lines is important to ensure that the logistics system can handle a wider range of products. Another important goal for scalability is enhancing the system's ability to handle fluctuations in demand without causing delays or bottlenecks in the system. Additionally, improving the scalability of the data processing and analysis capabilities is crucial to handle larger volumes of data. To support business growth, the system's ability to handle multiple warehouses, distribution centers, or shipping locations needs to be improved. Expanding into new markets requires the system to be able to handle a wider range of shipping methods and carriers. Finally, enhancing the system's ability to support new types of AI-driven logistics applications, such as predictive maintenance or autonomous vehicles, is also important to ensure that the system can evolve with the changing needs of the business.

Reliability

To start with the reliability criterion, increasing the uptime of the logistics system is essential to ensure that it is always available when needed. By reducing the number of system failures, errors, or downtime incidents that impact order fulfillment, transportation, or delivery, the system can be made more reliable. Additionally, improving the reliability of the system's hardware and software components will minimize the risk of hardware failures or software bugs. Increasing the system's ability to monitor and detect potential issues or anomalies in real-time can prevent or mitigate problems before they occur. It's also essential to improve the reliability of the system's data management and backup processes. This ensures that critical data is always available and protected, minimizing the risk of data loss or corruption. To achieve reliable performance, it's also important to increase the reliability of the system's AI models and algorithms. This ensures that they produce accurate and reliable results that can be trusted by logistics managers and stakeholders. The system should also provide real-time alerts and notifications to enable timely intervention in case of issues. Finally, the system should be designed to learn and adapt from failures or errors. This continuous improvement approach can help increase the system's reliability over time, making it more effective and efficient in meeting the needs of the business.

User-friendliness

When designing an AI-driven logistics system, user-friendliness should be a key criterion to consider. To ensure that the system is user-friendly, several goals should be pursued.

First and foremost, the system's overall ease-of-use must be improved to make it accessible and intuitive for all types of users. This can be achieved by simplifying the user interface, reducing the number of clicks required to complete tasks, and providing clear instructions. In addition, enhancing the system's user interface and user experience design can greatly improve the overall user experience. This can involve making the system more visually appealing, using more intuitive icons and menus, and providing feedback to users when they perform tasks. Another crucial goal is to increase the system's speed and responsiveness to reduce user frustration and improve productivity, particularly when users are under time pressure. Improving the system's navigation and search capabilities is also important to help users find the information and tools they need more quickly. This can be accomplished by providing better search functionality, organizing information logically, and providing clear labels for buttons and menu items. Moreover, enhancing the system's ability to personalize the user experience can improve user satisfaction and engagement. Personalization can involve tailoring the system to individual users' preferences, displaying relevant information based on their role or location, and offering customizable dashboards. Clear and concise documentation and training materials are also crucial to help users learn how to use the system effectively. This can involve providing video tutorials, user manuals, and online help resources. Furthermore, enhancing the system's error messages and feedback mechanisms can help users diagnose and fix issues when something goes wrong. Providing clear and actionable information can help users quickly resolve problems and get back to their work. Increasing the system's ability to provide proactive alerts and notifications can also help users stay on top of critical tasks and deadlines. This can include reminders about upcoming deliveries, alerts about out-of-stock items, and notifications about changes in order status. Finally, improving the system's ability to integrate with other tools and systems that users rely on can provide a seamless and cohesive user experience. Integrations with other systems, such as customer relationship management (CRMs) or enterprise resource planning (ERPs), can help users access all the information they need in one place.

Cost-effectiveness

Cost-effectiveness is an important criterion that can be achieved through various goals. Some of these goals include reducing the overall cost of transportation and delivery, improving the accuracy of demand forecasting and inventory management, increasing the efficiency of warehouse operations, and reducing the cost of labor and other operational expenses.

Effective management of internal transportation can help reduce costs and improve overall efficiency within a warehouse or enterprise. By optimizing transportation routes and carriers, organizations can minimize the time and resources required for moving goods and materials from one point to another within their facilities. This can be achieved by leveraging data from various sources, such as historical shipping data, real-time traffic information, and warehouse layout information. Another goal for cost-effectiveness is to improve the accuracy of demand forecasting and inventory management. By reducing excess inventory and minimizing stockouts, logistics companies can reduce their costs while still ensuring that they can meet customer demand. Efficiency in warehouse operations can be achieved by optimizing layouts, processes, and labor utilization. This involves using AI to analyze and optimize workflows, reducing the time and resources needed to complete tasks. To reduce the cost of labor and other operational expenses, logistics companies can automate routine tasks, processes and material handling tasks using AI and other technologies. This not only reduces labor costs but also improves accuracy and consistency in operations. Enhancing the system's ability to identify and mitigate sources of waste or inefficiency in the supply chain is another goal for cost-effectiveness. This can be achieved by analyzing data from various sources, including sensors, GPS, and RFID tags, to identify opportunities for optimization. Increasing the system's ability to analyze and optimize the total cost of ownership of logistics assets, such as vehicles, equipment, and facilities, is another way to improve cost-effectiveness. This involves using AI to analyze the costs associated with various assets and optimizing their use and maintenance. Improving the system's ability to negotiate and manage contracts with suppliers, carriers, and other logistics partners is another goal for cost-effectiveness. By ensuring favorable terms and pricing, logistics companies can reduce their costs and improve profitability. Enhancing the system's ability to track and report on key performance metrics, such as cost per order, cost per mile, and cost per unit, is another way to enable data-driven decision-making. By analyzing these metrics, logistics companies can identify opportunities for improvement and optimize their operations accordingly. Increasing the system's ability to simulate and model different scenarios and outcomes is another way to evaluate the cost-effectiveness of different strategies and approaches. Logistics companies can identify the most effective approaches and optimize their operations accordingly by testing different hypotheses and ideas in a low-risk environment. Finally, improving the system's ability to support continuous improvement and optimization is crucial for long-term cost-effectiveness. Logistics companies can continually improve their operations and stay competitive in a constantly changing marketplace by enabling stakeholders to test and validate different ideas and approaches.

Ethical and legal compliance

An AI-driven logistics system must adhere to ethical and legal compliance criteria to ensure that it operates in a responsible and sustainable manner. Here are some examples of goals that can be pursued to meet this criterion:

One crucial goal is to ensure that the system complies with all relevant local, national, and international laws and regulations. This involves adhering to data protection and privacy laws, transportation safety regulations, and environmental regulations. Another important goal is to implement appropriate safeguards to protect the privacy and security of customer and employee data. This can be done by implementing data encryption, access controls, and conducting regular security audits. A third goal is to ensure that the system's algorithms and decision-making processes do not discriminate against certain groups of individuals or violate their human rights. Regular audits and testing for bias and discrimination can help prevent such violations. A fourth goal is to establish clear and transparent ethical guidelines and standards for the use of AI in logistics. All stakeholders must understand and adhere to these standards, which will help promote ethical and responsible behavior. Another important goal is to monitor the system's performance and impact on social and environmental factors, such as emissions, energy consumption, and social responsibility. Steps can be taken to mitigate any negative effects and promote sustainability. Establishing clear processes and protocols for reporting and investigating any ethical or legal violations is also essential. Taking appropriate action to address such issues is crucial for maintaining ethical and legal compliance. The system's ethical and legal policies and procedures must be regularly reviewed and updated to ensure they remain current and relevant to changing business and regulatory environments. The system must be transparent and accountable to all stakeholders, and provide clear and accessible information about its operations, performance, and impact.

Security

To ensure the system's security, appropriate measures must be implemented, such as firewalls, antivirus software, and intrusion detection systems, to protect against cyber threats like hacking, malware, and phishing. Clear policies and procedures must also be established for secure data storage and transmission, including encryption, access controls, and data backup and recovery protocols. Regular security testing and assessments must be conducted to identify and address potential security weaknesses and vulnerabilities. All stakeholders should be trained and educated on security best practices and protocols, including password hygiene, social engineering awareness, and incident response procedures. A designated security officer or team should be responsible for managing and overseeing security-related activities. Physical security measures, like access controls, surveillance cameras, and alarms, should be implemented to protect facilities, equipment, and other assets from theft or unauthorized access. The system's activity should be monitored and logged to identify and respond to security incidents and threats in a timely manner. Partnerships and collaborations with external security organizations and stakeholders, such as law enforcement, industry associations, and cybersecurity experts, should be established and maintained to stay informed of emerging threats and best practices. The system's security policies and procedures should be regularly reviewed and updated to remain current and effective against evolving threats and risks. Finally, a culture of security awareness and responsibility should be fostered throughout the organization by promoting a collaborative and proactive approach to security management and response.

Integration

In order for an AI-driven logistics system to be effective, it must be able to seamlessly integrate with other systems and technologies used in logistics operations. This includes inventory management systems, transportation management systems, and warehouse management systems. To achieve this, clear standards and protocols for data exchange and communication between the system and other technologies must be established to ensure interoperability and compatibility. Furthermore, the system should provide application program interfaces (APIs) and other integration tools to facilitate integration with third-party systems and applications, such as e-commerce platforms, supplier portals, and customer relationship management systems. Regular testing and verification of the system's integration capabilities should be conducted to identify and resolve any integration issues or errors. Clear roles and responsibilities for integration management should be established, and an integration officer or team should be designated to oversee and manage integration-related activities. Regular training and education on integration best practices and protocols, such as data mapping, data transformation, and interface design, should be provided to all stakeholders. In addition, the organization should establish and maintain appropriate partnerships and collaborations with external integration organizations and stakeholders, such as technology vendors, standards organizations, and integration experts, to stay informed of emerging integration trends and best practices. Lastly, appropriate monitoring and reporting mechanisms should be implemented to track integration performance and identify opportunities for continuous improvement.

It's important to note that these specific goals for an AI-driven logistics system may vary depending on the needs of the logistics system and the stakeholders involved. While the examples mentioned above provide a general framework for optimizing logistics operations, it's crucial to tailor these goals to the unique challenges and opportunities that a particular logistics system faces. Furthermore, the stakeholders involved in the logistics system, such as suppliers, carriers, and customers, may have different priorities and preferences. Therefore, when designing an AI-driven logistics system, it's essential to involve all stakeholders and conduct a thorough analysis of their needs and expectations. By doing so, it's possible to develop a set of specific goals that align with the logistics system's objectives and deliver tangible benefits to all stakeholders involved.

4.2.2 Identifying the key performance indicators (KPIs)

Once the objectives have been defined, the next step is to identify the key performance indicators (KPIs) that will be used to measure the performance of the AI application in meeting these objectives and to define how each of them is calculated. KPIs are specific, measurable, and quantifiable performance metric used to track progress over time toward a particular objective or goal. They provide teams with targets to aim for, milestones to gauge progress, and insights to help guide decision-making throughout an organization. KPIs should be specific metrics that are closely tied to the objectives of the logistics system. Examples of KPIs could include delivery time, order accuracy, inventory turnover, transportation cost per unit, and customer satisfaction ratings. These metrics should be measurable, relevant, and time-bound to help track progress towards achieving the objectives of the logistics system. By identifying the appropriate KPIs, the evaluation model can ensure that the performance of the AI application is measured accurately and comprehensively.

They should also align with the key evaluation criteria, as this will help ensure that the evaluation model provides a comprehensive assessment of the AI application's performance. For example, if the objective is to reduce delivery times, the KPIs might include average delivery time, delivery time variance, and on-time delivery rate. If the objective is to minimize inventory levels, the KPIs might include inventory turnover rate, stockout rate, and order fill rate. By choosing KPIs that align with the objectives and key evaluation criteria, the evaluation model can provide a more accurate and useful assessment of the AI application's impact on the logistics system. This can help identify areas for improvement and support ongoing optimization of the system to achieve business goals. Table 4-1 presents a comprehensive list of KPIs that can be used to assess the performance of AI-driven logistics systems against the previously defined evaluation criteria.

Evaluation criterion	KPIs
Accuracy	Order fulfillment accuracy
	Misdeliveries/mis-ships
	Frequency of stockouts/overstocking
	Demand forecasting accuracy
	Order cancellations/returns
	Inventory management precision
	Automated picking/packing accuracy
	Supply chain delays/disruptions
	Billing/invoicing accuracy
Speed	Orders processed per time unit
	Order fulfillment time
	Order picking/packing time
	Data processing speed
	Issue/dispute resolution time
	Decision-making speed
	Reaction time to changing market conditions
Scalability	Order processing capacity
	Product line capacity
	Fluctuations in demand
	Multi-warehouse capacity
	Carrier diversity
Reliability	System uptime
	System downtime
	System failures
	Anomaly detection
	Real-time alerts and notifications
	Continuous improvement
User-friendliness	System accessibility
	User satisfaction
	System availability
	Search accuracy
	Personalization
	Documentation and training
	Error messages and feedback mechanisms
Cost-effectiveness	Internal transportation cost
	Inventory carrying cost
	Warehouse labor cost
	Contract compliance rate
	Order fulfillment time
	Order fulfillment accuracy
	Asset utilization rate

Ethical and legal compliance	Discrimination
	Ethical or legal violations
	Compliance with transportation safety regulations
	Compliance with data protection and privacy laws
	Energy consumption and emissions
	Social responsibility impact
	Algorithms and processes audited for bias and discrimination
	Frequency of ethical guideline
Security	Security incidents
	System downtime due to security incidents
	Response time to security incidents
	Conducted training and awareness
	Stakeholders' security
Integration	Successful integrations
	Resolved integration errors
	Time to complete integrations
	Third-party systems and applications integrated

Table 4-1: KPIs aligned with the evaluation criteria

Accuracy

- Order fulfillment accuracy: Percentage of orders fulfilled correctly on the first attempt. This percentage is calculated by dividing the number of orders fulfilled correctly on the first attempt by the total number of orders fulfilled.
- Misdeliveries/mis-ships: Misdeliveries or incorrect items shipped to customers. This ratio is calculated by dividing the total number of misdeliveries/mis-ships by the total number of orders shipped.
- Frequency of stockouts/overstocking: Number of times inventory runs out of stock or becomes overstocked per total number of items in inventory. The result is expressed as a ratio. Data on inventory levels and inventory movements, including sales and purchases is needed.
- Demand forecasting accuracy difference: Difference between predicted and actual demand for products. This KPI is calculated by subtracting the actual demand for a product from the predicted demand for that product, and then dividing the result by the actual demand, and expressing the result as a percentage.
- Order cancellations/returns: This KPI is calculated by dividing the total number of orders cancelled or returned due to inaccurate order fulfillment by the total number of orders fulfilled and expressing the result as a ratio.

- Inventory management precision: This KPI is calculated by subtracting the actual inventory levels from the inventory levels predicted by the system, and then dividing the result by the actual inventory levels, and expressing the result as a percentage.
- Automated picking/packing accuracy: This KPI is calculated by dividing the number of orders processed accurately by automated systems by the total number of orders processed by automated systems, and expressing the result as a percentage.
- Supply chain delays/disruptions: This KPI is calculated by dividing the total number of delays or disruptions in the supply chain due to inaccurate forecasting or planning by the total number of shipments, and expressing the result as a ratio.
- Billing/invoicing accuracy: This KPI is calculated by dividing the number of bills or invoices generated by the system that are accurate by the total number of bills or invoices generated by the system, and expressing the result as a percentage.

Speed

- Orders processed per time unit: This KPI can be calculated as the number of orders processed and shipped within a given time frame (week or month, for example), divided by the total number of orders received within that same time frame.
- Order fulfillment time: The average time it takes to fulfill an order over a certain period (day/week/month). This KPI can be calculated by adding up the order fulfillment times for all orders fulfilled over a certain period and dividing by the total number of orders fulfilled. The data needed for this calculation would be the timestamp of order placement and order fulfillment for each order.
- Order picking/packing time: The average time it takes to pick and pack an order over a certain period (day/week/month). This KPI can be calculated by adding up the order picking/packing times for all orders picked and packed over a certain period and dividing by the total number of orders picked and packed. The data needed for this calculation would be the timestamp of order picking and packing for each order.
- Data processing speed: The average time it takes to process and analyze data over a certain period (day/week/month). This KPI can be calculated by adding up the amount of data processed over a certain period and dividing by the time it took to process it. The data needed for this calculation would be the amount of data processed and the time it took to process it.
- Issue/dispute resolution time: The average time it takes to resolve issues or disputes related to orders, billing, or inventory management over a certain period (day/week/month). This can be calculated by adding up the resolution times

for all issues or disputes resolved over a certain period and dividing by the total number of issues or disputes resolved. The data needed for this calculation would be the timestamp of issue/dispute report and resolution for each issue or dispute.

- Decision-making speed: The average time it takes to make decisions based on insights and recommendations provided by the system over a certain period (day/week/month). This can be calculated by adding up the decision-making times for all decisions made over a certain period and dividing by the total number of decisions made. The data needed for this calculation would be the timestamp of decision request and decision made for each decision.
- Reaction time to changing market conditions: The average time it takes to respond to changing market conditions or unexpected events that impact the supply chain over a certain period (day/week/month). This can be calculated by adding up the reaction times for all market condition changes over a certain period and dividing by the total number of market condition changes. The data needed for this calculation would be the timestamp of market condition change and the system's response for each market condition change.

Scalability

- Order processing capacity: This KPI can be expressed by tracking the number of orders processed within a given time frame (hour/day/week/month).
- Product line capacity: This KPI can be obtained by determining the number of products or product lines the system can handle without causing any performance issues or inaccuracies in order processing. To obtain the data, it is necessary to track the system's performance and identify any inaccuracies or performance issues that may arise when processing different product lines.
- Fluctuations in demand: Percentage of orders fulfilled on time during peak demand periods. This can be calculated by dividing the number of orders fulfilled on time during peak demand periods by the total number of orders received during the same period.
- Multi-warehouse capacity: Number of warehouses or distribution centers the system can handle without causing any performance issues or inaccuracies in order processing. This can be calculated by analyzing the system's performance while processing orders from different warehouses or distribution centers. To obtain the necessary data, it is necessary to track the system's performance and identify any inaccuracies or performance issues that may arise when processing orders from different warehouses.
- Carrier diversity: Number of shipping methods and carriers the system can handle. This can be obtained by analyzing the system's performance while handling different shipping methods and carriers. It is necessary to track the system's

performance and identify any inaccuracies or performance issues that may arise when handling different shipping methods and carriers.

Reliability

- System uptime: Percentage of time that the logistics system is available and operational. This KPI can be obtained by dividing the total uptime of the system by the total time that the system should have been operational during a given time frame.
- System downtime: Percentage of time that the logistics system is unavailable due to a system failure. This KPI is calculated by dividing the total downtime due to system failures by the total time that the system should have been operational during a given time frame. To obtain the necessary data for this and the previous KPI, the system's uptime and downtime over time needs to be tracked, and the reasons for each downtime need to be identified.
- System failures: Number of system failures or errors that impact order fulfillment, transportation, or delivery. This KPI can be calculated by dividing the total number of system failures that impacted order fulfillment, transportation, or delivery by the total number of orders processed during a given time frame.
- Anomaly detection: Percentage of potential issues or anomalies that the system detects in real-time. This is calculated by dividing the number of potential issues or anomalies detected by the system in real-time by the total number of transactions or events that occurred during a given time frame. To obtain the necessary data, the system's performance needs to be tracked and any potential issues or anomalies that were detected in real-time identified.
- Real-time alerts and notifications: Percentage of alerts or notifications that are sent in real-time over time. This is obtained by dividing the number of alerts or notifications sent in real-time by the total number of alerts or notifications that were generated during a given time frame.
- Continuous improvement: Percentage of improvements made to the system following a failure or error over time. This can be obtained by dividing the number of improvements made to the system following a failure or error by the total number of failures or errors that occurred during a given time frame. To obtain the necessary data, it is necessary to track the system's performance and identify any failures or errors that occurred, as well as the improvements that were made to the system following each failure or error.

User-friendliness

- System accessibility: Percentage of users who can access and use the system without assistance or training. To calculate this, it is necessary to determine the total number of users who are able to access and use the system without assistance or training, and divide that by the total number of users who have attempted to access the system.

- User satisfaction: This KPI can be expressed as the average user satisfaction rating obtained from surveys or feedback mechanisms. To calculate this, it is necessary to collect user feedback through surveys or other feedback mechanisms and calculate the average satisfaction rating.
- System availability: This KPI can be expressed as the ratio of system uptime to system downtime. To calculate system uptime, the total amount of time that the system is available and operational is measured over a specific period. To calculate system downtime, the total uptime is subtracted from the total time in the measuring period. Once the total uptime and downtime are calculated, these values are used to calculate the system's availability ratio. The availability ratio is calculated by dividing the total uptime by the sum of the total uptime and downtime.
- Search accuracy: This KPI measures the percentage of search queries that return relevant and accurate results. To calculate this KPI, user search queries are tracked and compared the results to the actual information that the user was looking for. If the search query returns accurate and relevant results, it is marked as a success. If not, it is marked as a failure. The search accuracy is then calculated by dividing the total number of successful search queries by the total number of search queries.
- Personalization: This KPI can be expressed as the percentage of users who have personalized their experience and the frequency of usage of personalized features. To calculate this, the number of users who have personalized their experience is measured and expressed as a percentage of the total number of users.
- Documentation and training: This KPI can be expressed as the percentage of users who have completed the training materials and the number of support requests related to user errors or confusion. To calculate this, the number of users who have completed the training materials and the number of support requests related to user errors or confusion is calculated and divided by the total number of users.
- Error messages and feedback mechanisms: This KPI can be expressed as the ratio of resolved issues to the total number of issues reported. To calculate this, the number of errors and feedback messages received and the time taken by users to resolve the issue after receiving the feedback is measured. It can be expressed this as a ratio by dividing the number of resolved issues by the total number of issues reported.

Cost-effectiveness

- Internal transportation cost: This KPI is calculated by dividing the total internal transportation cost by the total number of units delivered within a given time frame. The total internal transportation cost is the sum of all costs associated with transporting goods within the logistics system. This includes costs such as fuel, maintenance, labor, and equipment costs, as well as any other costs directly related to the transportation of goods within the system. To calculate the total internal transportation cost, it is necessary to collect data on all of these costs from the logistics system, such as fuel receipts, maintenance logs, labor costs, and equipment depreciation. After that, the total internal transportation cost is calculated by adding up these cost data.
- Inventory carrying cost: This KPI is calculated by adding up the cost of holding inventory, including storage and handling costs, and dividing it by the average value of inventory. The cost of holding inventory includes various expenses such as storage costs, handling costs, insurance, obsolescence, and the cost of capital tied up in inventory. To calculate the inventory carrying cost, it is necessary to first determine the total cost of holding inventory over a specific period. This could include expenses such as rent or mortgage payments, utilities, labor costs for handling and managing inventory, insurance, taxes, and depreciation of equipment used for storing inventory. Once the total cost of holding inventory is determined, this figure is divided by the average value of inventory over the same period. The average value of inventory can be calculated by adding the beginning and ending inventory values for the period and dividing by two.
- Warehouse labor cost: This KPI is calculated by dividing the total labor cost in the warehouse by the total number of units handled in the warehouse. The resulting value will be a ratio expressed as labor cost per unit. To calculate the total labor cost for the warehouse, all the costs associated with the labor required to handle the units in the warehouse are taken into account. This can include salaries, wages, benefits, and any other related costs such as payroll taxes, employee training expenses, and insurance. To calculate the total labor cost for the warehouse, all of these costs for a given period of time, such as a week or a month, are added up.
- Contract compliance rate: Percentage of contracts that are being followed as agreed upon with the logistics partners. This KPI is expressed as a percentage of the total number of orders. To calculate this KPI, it is necessary to have a record of all the contracts with the logistics partners, along with the terms and conditions of those contracts, and divide the total number of contracts that are currently in effect by the total number of contracts. contracts with logistics partners can have a significant impact on the cost of logistics operations. For example, a contract that specifies a fixed price for the transportation of goods can

help to reduce transportation costs by providing a predictable cost structure. Similarly, a contract that specifies minimum order quantities can help to reduce the cost of handling and processing orders.

- Order fulfillment time: This KPI has already been explained in the group of KPIs for the criterion “speed”. It is a KPI that belongs to both the speed and cost-effectiveness criterion groups because it provides valuable information about the speed and efficiency of logistics operations as well as its impact on the cost of operations, labor, inventory, etc.
- Order fulfillment accuracy: This KPI has already been explained in the group of KPIs for the criterion “accuracy”. This KPI also belongs to two different criterion groups: accuracy and cost-effectiveness. Order fulfillment accuracy, besides the accuracy, is an important KPI for measuring the cost-effectiveness of logistics operations. Inaccurate order fulfillment can result in increased labor costs, higher inventory carrying costs, and potential lost sales.
- Asset utilization rate: This KPI is calculated by dividing the total time that logistics assets, such as vehicles, equipment, and facilities, are being used by the total available time.

Ethical and legal compliance

- Discrimination: This KPI is calculated as the number of discrimination or bias complaints and investigations that occurred during the specified period divided by the total number of employees and customers.
- Ethical or legal violations: This KPI is calculated as the number of ethical or legal violations reported and investigated that occurred during the specified period divided by the total number of employees and customers.
- Compliance with transportation safety regulations: This KPI is calculated as the ratio of compliance with transportation safety regulations to the total number of transportation activities carried out during the specified period.
- Compliance with data protection and privacy laws: This KPI measures the percentage of compliance with data protection and privacy laws. To calculate this KPI, the number of compliance violations related to data protection and privacy laws during the specified time period is divided by the total number of data protection and privacy laws that apply.
- Energy consumption and emissions: This KPI measures the amount of energy consumed and greenhouse gas emissions produced during transportation activities, and compares it to a set target for reduction. It is calculated by dividing the total energy consumption and emissions produced during transportation activities by the total number of transportation activities conducted during a specified period. Once this ratio is determined, it can be compared to a set target for

reducing energy consumption and emissions. This target could be a percentage reduction from a baseline measurement or a specific amount of energy or emissions reduction to achieve.

- Social responsibility impact: This KPI measures the percentage of social responsibility impact measurements that meet the desired standards. To calculate this KPI, the number of social responsibility impact measurements that meet the desired standards during the specified time period is divided by the total number of social responsibility impact measurements carried out.
- Algorithms and decision-making processes audited for bias and discrimination: To calculate this KPI, divide the number of algorithms and decision-making processes audited for bias and discrimination during the specified time period by the total number of algorithms and decision-making processes that exist
- Frequency of ethical guideline and standard updates: To calculate this KPI, the number of updates to ethical guidelines and standards is counted during the specified time period.

Security

- Security incidents: Number of security incidents reported and resolved within a specified time frame as a percentage of the total number of security incidents reported during that time frame.
- System downtime due to security incidents: Percentage of total system uptime lost due to security incidents. To calculate the percentage of system downtime due to security incidents, the number of hours of downtime due to security incidents is by the total number of hours of downtime within specified time frame.
- Response time to security incidents: Average time to detect and respond to security incidents.
- Conducted training and awareness: This KPI can be expressed as a percentage of employees who have completed security training, based on the total number of employees who need to take the training.
- Stakeholders' security: This KPI can be expressed as the number of security incidents affecting stakeholders (e.g., customers, partners, suppliers), per month or year.

Integration

- Successful integrations: This KPI measures the number of successful integrations with other logistics technologies within a specified time frame. It is calculated by dividing the number of successful integrations by the total number of attempted integrations and expressing it as a percentage.
- Resolved integration errors: This KPI measures the number of integration issues or errors resolved within a specified time frame. It is calculated by dividing

the number of resolved integration errors by the total number of integration errors and expressing it as a percentage.

- Time to complete integrations: This KPI measures the time taken to complete integration with other logistics technologies. It is calculated by dividing the total time taken to complete integrations by the number of integrations completed and expressed as an average time taken in hours, days, or weeks.
- Third-party systems and applications integrated: This KPI measures the number of training and education sessions conducted for stakeholders related to integration. It is expressed as a count.

By choosing KPIs that are aligned with the key evaluation criteria, organizations can ensure that the AI-driven operational logistics system is assessed in the best way possible. This can help identify areas for improvement and support ongoing optimization of the system to achieve business goals while meeting ethical and legal standards. However, it is important to note that these KPIs may not be exhaustive, and the specific KPIs needed for an AI-driven logistics system may vary depending on the system's characteristics and the stakeholders involved. Moreover, each stakeholder may prioritize different KPIs based on their specific needs and expectations. Thus, this list of KPIs can serve as a general framework to guide the evaluation process, but stakeholders may need to customize it based on their specific requirements.

4.2.3 Developing the scoring system for different AI applications of a logistics system

In this step, the focus is on the development of a scoring system for evaluating and comparing different AI applications from a company's logistics system. Key criteria, objectives, and KPIs aligned with each criterion and objective have been identified. The scoring system aims to provide a quantitative assessment of how well each AI application of a company meets the criteria. Weighted scores are assigned to each KPI and criterion to obtain a global score that reflects the overall performance of a specific AI application and is comparable to other AI applications within the same logistics system. This chapter presents a step-by-step process for developing the scoring system, including the selection of weights for each KPI and criterion, and a detailed explanation of how to calculate the scores. The scoring system enables the company to compare the score to the ideal value (baseline), track the progress of their AI applications' performance since the last evaluation, and take action based on the score.

Additionally, the resulting scoring system will enable companies to benchmark their AI-driven logistics systems against industry standards and identify areas for improvement. This scoring system provides a powerful tool for companies to evaluate the effectiveness of their AI-driven logistics systems and make data-driven decisions to optimize their operations.

			AI application 1		AI application 2		AI application 3	
		Weighting factor	Evaluation	Part utility	Evaluation	Part utility	Evaluation	Part utility
Criterion 1	KPI 1 criterion 1	0,1	6	0,6	5	0,5	2	0,2
	KPI 2 criterion 1	0,2	4	0,8	4	0,8	2	0,4
	KPI 3 criterion 1	0,1	8	0,8	4	0,4	3	0,3
	KPI 4 criterion 1	0,1	2	0,2	1	0,1	5	0,5
	Total criterion 1	**0,5**		**2,4**		**1,8**		**1,4**
Criterion 2	KPI 1 criterion 2	0,05	7	0,35	9	0,45	6	0,3
	KPI 2 criterion 2	0,1	9	0,9	8	0,8	5	0,5
	KPI 3 criterion 2	0,05	5	0,25	9	0,45	5	0,25
	KPI 4 criterion 2	0,1	6	0,6	6	0,6	3	0,3
	Total criterion 2	**0,3**		**2,1**		**2,3**		**1,35**
Criterion 3	KPI 1 criterion 3	0,05	3	0,15	1	0,05	9	0,45
	KPI 2 criterion 3	0,05	5	0,25	6	0,3	7	0,35
	KPI 3 criterion 3	0,05	1	0,05	4	0,2	2	0,1
	KPI 4 criterion 3	0,05	6	0,3	2	0,1	3	0,15
	Total criterion 3	**0,2**		**0,75**		**0,65**		**1,05**
	Total AI application utility			**5,25**		**4,75**		**3,8**

Table 4-2: Scoring system for AI applications - Generic version

Table 4-2 shows the scoring system that is used to evaluate the performance of three different AI applications based on three different criteria (Criterion 1, Criterion 2, and Criterion 3) and their respective KPIs. It's important to note that the scoring system presented in Table 4-2 is just a general version and starting point or template for the explanation of its working, but it will need to be adapted and tailored to the specific requirements and objectives of the evaluation process. In the next phases, the criteria and KPIs previously defined for each criterion will be employed instead of referring to them as "criterion 1, 2 and 3" and "KPI 1 criteria 1, KPI 1 criteria 2, etc.". Moreover, the weightage accorded to each criterion and KPI is here assigned randomly for the example but it will be substantiated in the next phases by providing a rationale.

Each KPI aligned with a criterion is assigned a relative KPI weighting factor (ranging from 0 to 1) and is multiplied by the criterion weighting factor (ranging from 0 to 1) to obtain the absolute KPI weighting factor, which indicates its importance in evaluating the AI application's performance for a particular criterion. For each KPI, the AI application is given an evaluation score (ranging from 0 to 10) which represents its performance against that particular KPI.

The "Part utility" column shows the product of the weighting factor and the evaluation score for each KPI, which is used to calculate the total utility of the AI application for a particular criterion. The "Total criterion" column shows the sum of the "Part utility" column for all KPIs under that criterion. For example, to calculate the score for Criterion 1, the score for KPI 1 is multiplied by 0.1, the score for KPI 2 is multiplied by 0.2, the score for KPI 3 is multiplied by 0.1, and the score for KPI 4 is multiplied by 0.1. These values are then added up to obtain the total score for Criterion 1.

Finally, the "Total AI application utility" column shows the total utility (ranging form 0 to 10) of each AI application, which is the sum of the "Total criterion" column for all criteria. Based on this example, AI application 1 has the highest utility score (5.25), followed by AI application 2 (4.75) and AI application 3 (3.8).

In order to obtain a score from 0 to 10 for each AI application (both partial for each criterion and global), it is necessary to normalize all the KPI values, so that they are also rated from 0 to 10 (0 being the worst and 10 the best possible score). To do this, the first thing to consider is that there are different types of KPIs among those selected for each evaluation criterion.

To obtain a score ranging from 0 to 10 for each AI application, encompassing both partial evaluation for each criterion and an overall assessment, it is imperative to standardize all the KPI values. This ensures that the KPI values are also rated on a scale from 0 to 10, with 0 being the worst possible score and 10 representing the best. The initial step towards achieving this involves considering the different types of KPIs chosen for each evaluation criterion. The majority of the KPIs are expressed as percentages or ratios, with values ranging between 0 and 1, and as average values within a certain time frame. Conversely to the percentage KPIs, certain ratios, such as cost per item and counts per unit of time, may have values exceeding 1. Additionally, counts may not necessarily have to be expressed per unit of time, as they can also be absolute values.

When calculating the score of KPIs out of 10, it is important to consider whether the KPI is meant to be maximized or minimized. It is important to standardize the scores to ensure that a good KPI that is meant to be minimized can still have a high score of 9 out of 10, and a good KPI that is meant to be maximized can also have a score of 9 out of 10. For example, when normalizing the KPI value of "system uptime," it is crucial to bear in mind that a higher KPI value represents better performance, thus resulting in a higher score. Conversely, for the KPI "inventory carrying cost," a higher value is indicative of poor performance, resulting in a lower score. Therefore, it is essential to apply the appropriate standardization method depending on whether the KPI is meant to be maximized or minimized. Consequently, it is imperative to employ distinct formulas for the linear normalization of KPI values based on whether the KPIs are to be maximized or minimized. To elaborate further, one formula will be implemented for KPIs that require maximization, whereas another formula will be utilized for those that require minimization. These formulas are presented below:

$$S_{max}(KPI_{act}) = \begin{cases} 0, & KPI_{act} \leq KPI_{min} \\ \dfrac{KPI_{act} - KPI_{min}}{KPI_{max} - KPI_{min}} * 10, & KPI_{min} < KPI_{act} < KPI_{max} \\ 10, & KPI_{act} \geq KPI_{max} \end{cases}$$

$$S_{min}(KPI_{act}) = \begin{cases} 0, & KPI_{act} \geq KPI_{max} \\ \frac{KPI_{max} - KPI_{act}}{KPI_{max} - KPI_{min}} * 10, & KPI_{min} < KPI_{act} < KPI_{max} \\ 10, & KPI_{act} \leq KPI_{min} \end{cases}$$

$\boldsymbol{S_{max}}$: $Score\ of\ the\ KPI_{act}\ value\ to\ be\ maximized$

$\boldsymbol{S_{min}}$: $Score\ of\ the\ KPI_{act}\ value\ to\ be\ minimized$

$\boldsymbol{KPI_{act}}$: $Actual\ KPI\ value\ to\ be\ normalized$

$\boldsymbol{KPI_{min}}$: $Value\ below\ which\ KPI_{act}\ would\ score\ 0\ (maximizing\ case), or\ 10\ (minimizing\ case)$

$\boldsymbol{KPI_{max}}$: $Value\ above\ which\ KPI_{act}\ would\ score\ 10\ (maximizing\ case), or\ 0\ (minimizing\ case)$

Using this formula, the minimum KPI_{act} value will be mapped to a score of 0, the maximum KPI_{act} value will be mapped to a score of 10 (or vice versa if it is a KPI to be minimized), and all other values will be linearly interpolated between these two endpoints. To calculate the S_{max} or S_{min} for every KPI_{act}, it is first necessary to define the values of KPI_{max} and KPI_{min} for each KPI_{act}. Note that this formula assumes a linear relationship between the KPI values and the corresponding scores, which may be more or less appropriate depending on the values given to KPI_{max} and KPI_{min}.

By setting these values, companies can establish performance benchmarks and assess how well their logistics systems are performing relative to their own ideal expectations and those of their competitors. Below, the main sources of information to define KPI_{max} and KPI_{min} are stated.

Companies must establish their own ideal situation. Note that the KPI_{max} and KPI_{min} values represent the best possible situation with a score of 10 and the worst situation with a score of 0 (or vice versa if it is a KPI to be minimized). This is the highest possible value that a logistics system could achieve for a given KPI under optimal conditions. By establishing an ideal value, companies can set a benchmark for what they hope to achieve and can use this value to measure progress towards their goals.

Companies can also establish KPI_{max} and KPI_{min} values based on the performance of their competitors. By benchmarking against the competition, companies can identify areas where they are falling behind and work to improve their logistics system's performance in those areas looking for the ideal results. Organizations may also need to establish KPI_{max} and KPI_{min} values based on performance standards set by industry associations or regulatory bodies. For example, if there are established standards for system uptime or order fulfillment rates in the logistics industry, companies may want to use these values as a benchmark for their ideal performance. Companies can use historical data to establish KPI_{max} and KPI_{min} values for each KPI. By looking at the performance of their logistics systems over time, organizations can identify trends and patterns in their performance and establish ideal/perfect benchmarks based on their own past performance. Finally, companies should establish KPI_{max} and KPI_{min} values based on their own business objectives. By setting these values, the company can track progress towards their goal and identify areas where they need to improve.

By adopting this approach, companies can gain a clearer understanding of how to assign the highest and lowest possible values to each KPI_{max} and KPI_{min}, thereby enabling them to standardize KPI scores through linear normalization in the most suitable manner.

Once S_{max} or S_{min} have been calculated for each KPI, the weighting factors of each criterion and KPI must be determined. To determine the weights of each criterion, the Analytic Hierarchy Process (AHP) method will be used. AHP is designed to help decision-makers evaluate and prioritize different criteria or alternatives based on their relative importance.

First, pairwise comparisons need to be made for each criterion against all other criteria in terms of their relative importance. A scale of 1 to 9 can be used for this purpose, where 1 means that the two criteria are equally important and 9 means that one criterion is extremely more important than the other. For instance, if accuracy is considered to be slightly more important than speed, a score of 3 should be assigned to accuracy and 1/3 to speed. Table 4-3 shows the pairwise comparison scores for all the criteria:

Criteria	Accuracy	Speed	Scalability	Reliability	Cost-effective-ness	User-friendliness	Ethical and legal compliance	Security	Integration
Accuracy	1	3	9	7	5	7	8	3	9
Speed	1/3	1	3	2	1/2	2	3	1	3
Scalability	1/9	1/3	1	1/2	1/4	1/2	1	1/3	1
Reliability	1/7	1/2	2	1	1/3	2	3	1/2	2
Cost-effective-ness	1/5	2	4	3	1	3	5	2	5
User-friendliness	1/7	1/2	2	1/2	1/3	1	2	1/2	2
Ethical and legal compliance	1/8	1/3	1	1/3	1/5	1/2	1	1/4	1
Security	1/3	1	3	2	1/2	2	4	1	3
Integration	1/9	1/3	1	1/2	1/5	1/2	1	1/3	1

Table 4-3: Criteria pairwise comparison score for AHP

To calculate the weights for each criterion, the normalized weight for each row of the table is calculated by dividing each element in the row by the sum of the elements in that row. For example, to calculate the normalized weight for the row of the "accuracy" criterion, all scores in that row need to be added up (1+3+9+7+5+7+8+3+9 = 52). The elements of this sum are then divided by 52 to get the normalized weights for each element in that row. This can be seen in Table 4-4 for every row.

Criteria	Accuracy	Speed	Scalability	Reliability	Cost-effective-ness	User-friendli-ness	Ethical and legal compliance	Security	Integration
Accuracy	0,019	0,058	0,173	0,135	0,096	0,135	0,154	0,058	0,173
Speed	0,021	0,063	0,189	0,126	0,032	0,126	0,189	0,063	0,189
Scalability	0,022	0,066	0,199	0,099	0,050	0,099	0,199	0,066	0,199
Reliability	0,012	0,044	0,174	0,087	0,029	0,174	0,261	0,044	0,174
Cost-effective-ness	0,008	0,079	0,159	0,119	0,040	0,119	0,198	0,079	0,198
User-friendli-ness	0,016	0,056	0,223	0,056	0,037	0,111	0,223	0,056	0,223
Ethical and le-gal com-pliance	0,026	0,070	0,211	0,070	0,042	0,105	0,211	0,053	0,211
Security	0,020	0,059	0,178	0,119	0,030	0,119	0,238	0,059	0,178
Integration	0,022	0,067	0,201	0,100	0,040	0,100	0,201	0,067	0,201

Table 4-4: Normalized weights per rows

To calculate the weighted average for each criterion (that means for each row), each element in the row needs to be multiplied by the corresponding element of the row from Table 4-3, and summed. For instance, to determine the weight for the "Accuracy" criterion, the normalized weight for each element in the "accuracy" row is multiplied by the corresponding element in the pairwise comparison table. The resulting products are then added together:

Weight for accuracy = (0,019*1) + (0,058*3) + (0,173*9) + (0,135*7) + (0,096*5) + (0,135*7) + (0,154*8) + (0,058*3) + (0,173*9) = 7,077

Criteria	Weighted Average
Accuracy	7,077
Speed	2,360
Scalability	0,755
Reliability	1,972
Cost-effectiveness	3,692
User-friendliness	1,546
Ethical and legal compliance	0,757
Security	2,635
Integration	0,758

Table 4-5: Weighted average for every criterion

The last step of the AHP is to normalize these weights by dividing each weighted average by the sum of all the weighted averages, as shown in Table 4-6:

Criteria	Weighted Average
Accuracy	0,328
Speed	0,109
Scalability	0,035
Reliability	0,091
Cost-effectiveness	0,171
User-friendliness	0,072
Ethical and legal compliance	0,035
Security	0,122
Integration	0,035

Table 4-6: Normalized weighting factors for every criterion

These are the criteria weighting factors that are going to be used to evaluate the performance of AI applications in logistics determined with the help of the AHP method. This study provides with some insights and an example on how to approach the task of defining a weighting factor for every evaluation criterion. However, it's important to note that the optimal weighting of these factors depends on the specific context and requirements of the logistics system the company is evaluating. Therefore, this is a general guideline and realistic example, and companies should consider adapting it to their specific case.

Once the criteria weights were established, the KPIs for each criterion were defined and the corresponding weighting factors were assigned. Judgment was used based on knowledge and experience in the logistics field, as well as available literature and best practices, to assign weights that reflect the relative importance of the KPIs in achieving the overall system objectives in an appropriate and suitable manner. The KPI weighting factors table presented in this report summarizes the weights assigned to each KPI for every criterion, providing a comprehensive view of the evaluation system structure. Table 4-7 is considered a valuable tool for decision-makers, serving as an example of choosing the KPI weighting factors.

Evaluation criterion	KPIs	Relative KPI weight	Absolute KPI weight
Accuracy (0,328)	Order fulfillment accuracy	0,2	0,066
	Misdeliveries/mis-ships	0,15	0,049
	Frequency of stockouts/overstocking	0,1	0,033
	Demand forecasting accuracy	0,15	0,049
	Order cancellations/returns	0,1	0,033
	Inventory management precision	0,1	0,033
	Automated picking/packing accuracy	0,1	0,033
	Supply chain delays/disruptions	0,05	0,016
	Billing/invoicing accuracy	0,05	0,016
Speed (0,109)	Orders processed per time unit	0,2	0,022
	Order fulfillment time	0,25	0,027
	Order picking/packing time	0,15	0,016
	Data processing speed	0,1	0,011
	Issue/dispute resolution time	0,1	0,011
	Decision-making speed	0,1	0,011
	Reaction time to changing market conditions	0,1	0,011
Scalability (0,035)	Order processing capacity	0,25	0,009
	Product line capacity	0,2	0,007
	Fluctuations in demand	0,2	0,007
	Multi-warehouse capacity	0,2	0,007
	Carrier diversity	0,15	0,005

Reliability (0,091)	System uptime	0,2	0,018
	System downtime	0,2	0,018
	System failures	0,2	0,018
	Anomaly detection	0,2	0,018
	Real-time alerts and notifications	0,1	0,009
	Continuous improvement	0,1	0,009
User-friendliness (0,171)	System accessibility	0,1	0,017
	User satisfaction	0,2	0,034
	System availability	0,2	0,034
	Search accuracy	0,15	0,026
	Personalization	0,1	0,017
	Documentation and training	0,15	0,026
	Error messages and feedback mechanisms	0,1	0,017
Cost-effectiveness (0,072)	Internal transportation cost	0,25	0,018
	Inventory carrying cost	0,2	0,014
	Warehouse labor cost	0,2	0,014
	Contract compliance rate	0,1	0,007
	Order fulfillment time	0,15	0,011
	Order fulfillment accuracy	0,05	0,004
	Asset utilization rate	0,05	0,004
Ethical and legal compliance (0,035)	Discrimination	0,15	0,005
	Ethical or legal violations	0,15	0,005
	Compliance with transportation safety regulations	0,1	0,004
	Compliance with data protection and privacy laws	0,2	0,007
	Energy consumption and emissions	0,15	0,005
	Social responsibility impact	0,1	0,004
	Algorithms and processes audited for bias and discrimination	0,1	0,004
	Frequency of ethical guideline	0,05	0,002
Security (0,122)	Security incidents	0,3	0,037
	System downtime due to security incidents	0,2	0,024
	Response time to security incidents	0,2	0,024
	Conducted training and awareness	0,2	0,024
	Stakeholders' security	0,1	0,012
Integration (0,035)	Successful integrations	0,35	0,012
	Resolved integration errors	0,25	0,009
	Time to complete integrations	0,25	0,009
	Third-party systems and applications integrated	0,15	0,005

Table 4-7: Absolute KPI weighting factors

The column designated as "absolute KPI weight" from Table 4-7 contains the absolute values of the weights assigned to each KPI (Absolute KPI weight = Relative KPI weight * Criterion weight). This table is essential for the evaluation of different AI applications in logistics.

In summary, this work has provided a comprehensive explanation of the evaluation table and its scoring system. The operation of the system has been presented in terms of both rows and columns, and the process of standardizing the scores of each KPI to obtain a range from 0 to 10 has been detailed, including each element of the relevant formulas. Furthermore, this work has elucidated the AHP method for determining criteria weighting factors, and the resulting weighting factors assigned to each KPI have been presented.

4.2.4 Establishing a baseline

Before implementing the AI application, it's important to establish a baseline score for each KPI, resulting in a baseline score for each AI application. Establishing a baseline is a crucial step in evaluating AI-driven logistics systems, since this will provide a benchmark for evaluating the performance of the AI application.

Defining a fictional company and its AI applications in logistics

First, the AI applications that are being implemented in the organization need to be clearly defined. This includes identifying the specific AI technologies being used, such as machine learning algorithms, natural language processing, computer vision, or optimization algorithms, and their applications in the logistics context, such as demand forecasting, route optimization, warehouse management, or transportation scheduling. In the context of this study, an imaginary company that employs AI in its logistics operations will be introduced as an illustrative example for the evaluation process. The purpose of introducing this fictional company is to provide a hypothetical scenario that can be used to demonstrate the evaluation process outlined in this study.

LogiSmart Solutions is a hypothetical company that operates within a large manufacturing facility specializing in the production of electronic goods. As an internal logistics solutions provider, LogiSmart Solutions is responsible for managing the complex and dynamic movement of raw materials, components, and finished goods within the facility to support the smooth operation of the manufacturing process. The company leverages cutting-edge AI-driven logistics systems to streamline operations, optimize inventory management, and enhance overall efficiency. However, as a fictional company created solely for academic illustration, LogiSmart Solutions serves as an example for evaluating how a real company may approach the implementation and evaluation of an AI-driven logistics system in a manufacturing environment. The following analysis provides insights into the key considerations and best practices that a real company should take into account when establishing the baseline for the evaluation system.

The company has implemented two AI-driven applications to optimize their internal logistics operations:

The first AI-based implementation is the Automated Guided Vehicle (AGV) Fleet Management System, which is a sophisticated AI-driven application that manages a fleet of AGVs to efficiently transport materials and goods within the facility. It is a cutting-edge AI application that leverages advanced machine learning algorithms, real-time data processing, and sophisticated sensor technologies to optimize the movement of materials and goods within the facility. It enables efficient and reliable AGV operations, improving operational efficiency, reducing downtime, and enhancing overall internal logistics performance. Some of the features of the system are stated below:

The AGV Fleet Management System provides real-time monitoring and control of the entire AGV fleet operating within the facility. It uses sensors and communication technologies to track the location, status, and performance of each AGV in real-time. This allows the system to have full visibility and control over the AGV fleet at any given moment, enabling efficient coordination and management of AGV operations.

The system uses advanced machine learning algorithms to dynamically optimize the routing and scheduling of AGVs based on real-time demand from different areas of the facility. It considers factors such as AGV location, load capacity, priority of tasks, and production schedules to make intelligent decisions on the most optimal routes and schedules for AGVs. This helps to minimize travel time, reduce congestion, and improve overall efficiency in material handling operations.

The AGV Fleet Management System is equipped with advanced sensor technologies, such as cameras, lidar, and proximity sensors, that enable it to detect obstacles and prevent collisions. The system continuously monitors the environment around AGVs and uses real-time data to calculate safe routes and speeds to avoid collisions. This ensures safe and efficient AGV operations, minimizing the risk of accidents and damages to materials or goods.

It is designed to seamlessly integrate with other internal logistics systems and equipment, such as conveyors, elevators, and production scheduling systems. This allows for synchronized operations and coordinated movements of AGVs with other logistics processes, ensuring smooth material flow and optimized resource utilization. For example, the system can coordinate the movement of AGVs with the availability of materials at different production stations, reducing wait times and bottlenecks.

The second AI-driven application is the Inventory Optimization and Demand Forecasting System, which is an AI-driven application that optimizes inventory levels and forecasts demand to ensure efficient and cost-effective inventory management. It is a powerful AI application that leverages advanced machine learning algorithms, real-time data processing, and collaboration capabilities to optimize inventory levels, accurately forecast demand, and improve overall inventory management performance. It enables LogiSmart Solutions to optimize inventory levels, reduce stockouts, and improve customer service levels while minimizing inventory carrying costs and stockouts. The key features of the system are stated below:

The system uses advanced machine learning algorithms to analyze historical sales data, customer behavior, market trends, and other relevant factors to accurately forecast demand for different products or SKUs. The forecasting model takes into account various demand patterns, seasonality, and market dynamics to provide accurate demand forecasts at different time horizons, such as short-term, mid-term, and long-term. This helps LogiSmart Solutions to plan their inventory levels based on anticipated demand, reducing stockouts or overstocks.

The Inventory Optimization and Demand Forecasting System uses the demand forecasts, along with cost considerations such as holding costs, ordering costs, and stockout costs, to determine the optimal inventory levels for each product or SKU. The system automatically calculates and adjusts reorder points, safety stock levels, and order quantities based on the forecasted demand, desired service levels, and cost parameters. This ensures that inventory levels are optimized to meet customer demand while minimizing inventory carrying costs and stockouts.

It provides real-time visibility into inventory levels, stock movements, and replenishment status across different warehouses, distribution centers, or storage locations. It uses sensors, RFID tags, and other tracking technologies to capture real-time data on inventory levels and movements. This enables LogiSmart Solutions to have a holistic view of inventory across the supply chain and make data-driven decisions on inventory replenishment, stock transfers, and demand fulfillment.

The AI application enables collaboration with suppliers and customers for demand sharing and better demand visibility. The system allows for data sharing and integration with suppliers' systems and customers' systems, facilitating collaborative demand planning, forecasting, and replenishment. This helps to align inventory levels with demand fluctuations, reduce stockouts, and improve overall supply chain efficiency.

The system provides what-if analysis and scenario planning capabilities that allow LogiSmart Solutions to proactively assess the impact of different scenarios on inventory levels and make informed decisions. For example, the system can simulate the effect of changes in demand patterns, lead times, or ordering policies on inventory levels and service levels. This helps LogiSmart Solutions to proactively identify potential inventory risks and take corrective actions in a timely manner.

Establishing baseline scores for every KPI

Once the AI applications are defined, the next step is to establish baseline scores for each KPI that will be used to evaluate their performance. To obtain the baseline scores, historical data and existing performance records of the organization can be used as a reference. This data can provide insights into the current performance levels of the logistics systems without the implementation of AI applications. For example, delivery time, order accuracy, and on-time delivery percentage can be calculated based on past performance records, while cost per shipment and inventory turnover ratio can be obtained from financial and inventory management data.

In this study, the calculation of the scores of the KPIs with the highest weighting factor for each criterion (AI application 1) will be demonstrated as an illustrative example for companies seeking to adopt an evaluation process. However, the remaining KPI scores will not be calculated, but rather assigned in a concise and logical manner to complete the scoring system table (Table 4-8) with the baseline values without excessively prolonging the explanation.

$$\boldsymbol{Order\ fulfillment\ accuracy\ (Accuracy)} =$$

$$= \frac{\#\ of\ orders\ fulfilled\ correctly\ on\ the\ 1st\ attempt\ within\ a\ month}{Total\ \#\ of\ orders\ fulfilled\ within\ a\ month} = \frac{485}{500} = 0{,}97$$

$$\boldsymbol{S_{max,baseline}} = \frac{0{,}97 - 0{,}3}{1 - 0{,}3} * 10 = \mathbf{9{,}57}$$

$$\boldsymbol{Order\ processed\ per\ time\ unit\ (Speed)} =$$

$$= \frac{\#\ of\ orders\ processed\ and\ shipped\ within\ a\ week}{Total\ \#\ of\ orders\ received\ within\ a\ week} = \frac{135}{150} = 0{,}9$$

$$\boldsymbol{S_{max,baseline}} = \frac{0{,}9 - 0}{1 - 0} * 10 = \mathbf{9}$$

$\boldsymbol{Order\ processing\ capacity\ (Scalability)} =$

$$= \#\ of\ orders\ processed\ within\ a\ day\ = 35\ \frac{orders\ processed}{day}$$

$$\boldsymbol{S_{max,baseline}} = \frac{35 - 0}{40 - 0} * 10 = \mathbf{8{,}7}$$

$\boldsymbol{System\ downtime\ (Reliability)} =$

$$= \frac{Total\ downtime\ due\ to\ system\ failures\ within\ a\ month}{Total\ time\ the\ system\ should\ have\ been\ operational\ within\ a\ month} = \frac{2\ h}{720\ h} = 0{,}0028$$

$$\boldsymbol{S_{min,baseline}} = \frac{0{,}1 - 0{,}0028}{0{,}1 - 0} * 10 = \mathbf{9{,}72}$$

$\boldsymbol{User\ satisfaction\ (User - friendliness)}$

$$= \ average\ user\ satisfaction\ rating\ obtained\ from\ surveys\ or\ feedback\ mechanisms = 9$$

$$\boldsymbol{S_{max,baseline}} = \frac{9 - 0}{10 - 0} * 10 = \mathbf{9}$$

$\boldsymbol{Internal\ transportation\ cost\ (Cost - effectiveness)} =$

$$= \frac{Total\ internal\ transportation\ cost\ within\ a\ month}{Total\ \#\ of\ units\ (lots)\ delivered\ within\ a\ month} = \frac{10.000\ €}{700\ lots} = 14{,}286\ \frac{€}{lot}$$

$$\boldsymbol{S_{min,baseline}} = \frac{100 - 14{,}286}{100 - 7} * 10 = \mathbf{9{,}22}$$

$\boldsymbol{Compliance\ with\ data\ protection\ and\ privacy\ laws\ (Ethical\ and\ legal\ compliance)} =$

$$= \frac{\#\ of\ compliance\ violations\ related\ to\ data\ protection\ and\ privacy\ laws\ within\ a\ month}{Total\ \#\ of\ protection\ and\ privacy\ laws} = \frac{2}{100} = 0{,}02$$

$$\boldsymbol{S_{min,baseline}} = \frac{0{,}2 - 0{,}02}{0{,}2 - 0} * 10 = \mathbf{9}$$

$\boldsymbol{Security\ incidents\ (Security)} =$

$$= \frac{\#\ of\ security\ incidents\ reported\ and\ resolved\ within\ a\ month}{Total\ \#\ of\ security\ incidents\ reported\ within\ a\ month} = \frac{24}{25} = 0{,}96$$

$$\boldsymbol{S_{max,baseline}} = \frac{0{,}96 - 0{,}3}{1 - 0{,}3} * 10 = \mathbf{9{,}43}$$

$\boldsymbol{Successful\ integrations}\ (\boldsymbol{Integration}) =$

$$= \frac{\#\ of\ successful\ integrations\ since\ implemented}{Total\ \#\ of\ attempted\ integrations\ since\ implemeneted} = \frac{19}{20} = 0{,}95$$

$$\boldsymbol{S_{max,baseline}} = \frac{0{,}95 - 0}{1 - 0} * 10 = \mathbf{9{,}5}$$

			AI application 1				AI application 2			
		Relative KPI weight	Relative KPI weight applic. 1	Weighting factor ap-plic. 1	Evalua-tion	Part utility	Relative KPI weight applic. 2	Weighting factor ap-plic. 2	Evalua-tion	Part utility
Accuracy	Order fulfillment accuracy	0,2	0,2	0,069	9,570	0,661	0,2	0,069	9,750	0,673
	Misdeliveries/mis-ships	0,15	0,15	0,052	9,400	0,487	0,15	0,055	9,500	0,519
	Frequency of stockouts/overstocking	0,1	0,1	0,035	9,200	0,318	0,1	0,035	9,600	0,331
	Demand forecasting accuracy	0,15	0,15	0,052	8,000	0,414	0,15	0,052	9,750	0,505
	Order cancellations/returns	0,1	0,1	0,035	9,600	0,331	0,1	0,035	9,500	0,328
	Inventory management precision	0,1	0,1	0,035	9,400	0,325	0,1	0,035	9,800	0,338
	Automated picking/packing accuracy	0,1	0,1	0,035	9,750	0,337	0	0,000	N/A	0,000
	Supply chain delays/disruptions	0,05	0	0,000	N/A	0,000	0,05	0,017	9,500	0,164
	Billing/invoicing accuracy	0,05	0,05	0,017	9,500	0,164	0,05	0,017	9,600	0,166
	Total Accuracy			**0,328**		**3,036**		**0,328**		**3,025**
Speed	Orders processed per time unit	0,2	0,2	0,022	9,000	0,196	0	0,000	N/A	0,000
	Order fulfillment time	0,25	0,25	0,027	9,200	0,251	0	0,000	N/A	0,000
	Order picking/packing time	0,15	0,15	0,016	9,000	0,147	0	0,000	N/A	0,000
	Data processing speed	0,1	0,1	0,011	9,500	0,104	0,1	0,027	9,800	0,267
	Issue/dispute resolution time	0,1	0,1	0,011	9,700	0,106	0,1	0,027	9,700	0,264
	Decision-making speed	0,1	0,1	0,011	9,800	0,107	0,1	0,027	9,400	0,256
	Reaction time to changing market conditions	0,1	0,1	0,011	9,300	0,101	0,1	0,027	9,700	0,264
	Total Speed			**0,109**		**1,012**		**0,109**		**1,052**
Scalability	Order processing capacity	0,25	0,25	0,009	8,700	0,076	0	0,000	N/A	0,000
	Product line capacity	0,2	0,2	0,007	8,700	0,061	0,2	0,009	8,500	0,079
	Fluctuations in demand	0,2	0,2	0,007	9,000	0,063	0,2	0,009	9,500	0,089
	Multi-warehouse capacity	0,2	0,2	0,007	8,800	0,062	0,2	0,009	9,200	0,086
	Carrier diversity	0,15	0,15	0,005	8,800	0,046	0,15	0,007	8,000	0,056
	Total Scalability			**0,035**		**0,308**		**0,035**		**0,310**

Reliability	System uptime	0,2	0,2	0,018	9,720	0,177	0,2	0,018	8,800	0,160
	System downtime	0,2	0,2	0,018	9,720	0,177	0,2	0,018	8,800	0,160
	System failures	0,2	0,2	0,018	9,500	0,173	0,2	0,018	9,000	0,164
	Anomaly detection	0,2	0,2	0,018	9,600	0,175	0,2	0,018	9,200	0,167
	Real-time alerts and notifications	0,1	0,1	0,009	9,600	0,087	0,1	0,009	9,400	0,086
	Continuous improvement	0,1	0,1	0,009	8,900	0,081	0,1	0,009	8,800	0,080
	Total Reliability			**0,091**		**0,870**		**0,091**		**0,817**
User-freindliness	System accessibility	0,1	0,1	0,017	8,800	0,150	0,1	0,017	9,300	0,159
	User satisfaction	0,2	0,2	0,034	9,000	0,308	0,2	0,034	9,000	0,308
	System availability	0,2	0,2	0,034	9,500	0,325	0,2	0,034	9,500	0,325
	Search accuracy	0,15	0,15	0,026	8,500	0,218	0,15	0,026	9,000	0,231
	Personalization	0,1	0,1	0,017	8,000	0,137	0,1	0,017	8,500	0,145
	Documentation and training	0,15	0,15	0,026	9,200	0,236	0,15	0,026	9,200	0,236
	Error messages and feedback mechanisms	0,1	0,1	0,017	9,300	0,159	0,1	0,017	9,300	0,159
	Total User-friendliness			**0,171**		**1,533**		**0,171**		**1,563**
Cost-effectiveness	Internal transportation cost	0,25	0,25	0,020	9,220	0,184	0	0,000	N/A	0,000
	Inventory carrying cost	0,2	0,2	0,016	9,200	0,147	0,2	0,029	9,200	0,265
	Warehouse labor cost	0,2	0,2	0,016	9,400	0,150	0,2	0,029	9,400	0,271
	Contract compliance rate	0,1	0	0,000	N/A	0,000	0	0,000	N/A	0,000
	Order fulfillment time	0,15	0,15	0,012	9,200	0,110	0	0,000	N/A	0,000
	Order fulfillment accuracy	0,05	0,05	0,004	9,570	0,038	0,05	0,007	9,750	0,070
	Asset utilization rate	0,05	0,05	0,004	9,700	0,039	0,05	0,007	9,000	0,065
	Total Cost-effectiveness			**0,072**		**0,669**		**0,072**		**0,671**

Ethical and legal compliance	Discrimination	0,15	0	0,000	N/A	0,000	0	0,000	N/A	0,000
	Ethical or legal violations	0,15	0	0,000	N/A	0,000	0	0,000	N/A	0,000
	Compliance with transportation safety regulations	0,1	0,1	0,005	9,200	0,046	0,1	0,006	9,200	0,054
	Compliance with data protection and privacy laws	0,2	0,2	0,010	9,000	0,090	0,2	0,012	9,000	0,105
	Energy consumption and emissions	0,15	0,15	0,008	8,800	0,066	0,15	0,009	8,800	0,077
	Social responsibility impact	0,1	0,1	0,005	9,000	0,045	0	0,000	N/A	0,000
	Algorithms and processes audited for bias and discrimination	0,1	0,1	0,005	9,400	0,047	0,1	0,006	9,400	0,055
	Frequency of ethical guideline	0,05	0,05	0,003	8,800	0,022	0,05	0,003	8,800	0,026
	Total Ethical and legal compliance			**0,035**		**0,316**		**0,035**		**0,316**
Security	Security incidents	0,3	0,3	0,037	9,430	0,345	0,3	0,037	9,000	0,329
	System downtime due to security incidents	0,2	0,2	0,024	9,400	0,229	0,2	0,024	9,400	0,229
	Response time to security incidents	0,2	0,2	0,024	9,600	0,234	0,2	0,024	9,600	0,234
	Conducted training and awareness	0,2	0,2	0,024	9,200	0,224	0,2	0,024	9,200	0,224
	Stakeholders' security	0,1	0,1	0,012	9,300	0,113	0,1	0,012	9,300	0,113
	Total Security			**0,122**		**1,147**		**0,122**		**1,131**
Integration	Successful integrations	0,35	0,35	0,012	9,500	0,116	0,35	0,012	9,600	0,118
	Resolved integration errors	0,25	0,25	0,009	9,500	0,083	0,25	0,009	9,600	0,084
	Time to complete integrations	0,25	0,25	0,009	8,500	0,074	0,25	0,009	8,500	0,074
	Third-party systems and applications integrated	0,15	0,15	0,005	8,800	0,046	0,15	0,005	9,300	0,049
	Total Integration			**0,035**		**0,320**		**0,035**		**0,325**
	Total AI application utility					**9,211**				**9,210**

Table 4-8: Baseline scoring system

It's important to keep in mind that certain KPIs may be marked as "N/A" (not applicable) in the "Evaluation" column, rather than being assigned a score ranging from 0 to 10. This is because in some cases, the chosen KPI may not be meaningful or relevant to the specific AI application being evaluated. Thus, including it in the overall score would not provide accurate insights. This "N/A" designation indicates that the KPI does not apply to the particular AI application and should not be factored into the scoring process. KPIs that are marked with an evaluation of "N/A" are treated differently in the "Relative weighting factor AI application X" column. Instead of using the generic weight assigned to them in section 4.2.3 as stated in the "Relative KPI weight" column, they are automatically assigned a weight of 0. This means that these KPIs do not contribute to the overall evaluation of the specific AI application being assessed. On the other hand, KPIs that receive a numerical evaluation other than "N/A" retain the weight specified in the "Relative KPI weight" column in the "Relative weighting factor AI application X" column. This weight represents their new relative evaluation (uncorrected) and must be divided by the sum of all the new relative evaluations (uncorrected) of the criterion these KPIs belong to in order to recalculate the final relative weighting factor (corrected) of this KPI. By multiplying this final relative weighting factor with the total criterion weighting factor, the absolute weighting factor for this KPI (column “Weighting factor applic. X”) is obtained. The formula used for this calculation for a particular AI application is determined as follows:

$$(\boldsymbol{Abs.WF})_{\boldsymbol{ij}} = (Final\ Rel.WF)_{ij} * WF_i = \frac{(Rel.WF)_{ij}}{\sum_{j=1}^{N_i}(Rel.WF)_{ij}} * WF_i$$

$\forall\ i \in I : criteria$

$\forall\ j \in N_i : KPIs$

$(\boldsymbol{Abs.WF})_{\boldsymbol{ij}} : Absolute\ WF\ for\ KPI\ j\ from\ criterion\ i$

$(\boldsymbol{Final\ Rel.WF})_{\boldsymbol{ij}} : Final\ relative\ WF\ for\ KPI\ j\ from\ criterion\ i$

$(\boldsymbol{Rel.WF})_{\boldsymbol{ij}} : Relative\ WF\ (uncorrected)\ for\ KPI\ j\ from\ criterion\ i$

$\boldsymbol{WF_i} : Total\ WF\ for\ criterion\ i$

$\boldsymbol{N_i} : Number\ of\ KPIs\ under\ criterion\ i$

Here is the computation for the absolute weighting factor (found in the "Weighting factor applic. 1" column) of the "order fulfillment accuracy" KPI that falls under the "accuracy" criterion for AI application 1, as illustrated in Table 4-8.

$$(\boldsymbol{Abs.WF})_{\mathbf{11}} = \frac{(Rel.WF)_{11}}{\sum_{j=1}^{N_1}(Rel.WF)_{1j}} * WF_1 =$$

$$= \frac{0{,}2}{0{,}2 + 0{,}15 + 0{,}1 + 0{,}15 + 0{,}1 + 0{,}1 + 0{,}1 + 0 + 0{,}05} * 0{,}328 = \mathbf{0{,}069}$$

In accordance with the methodology outlined in section 4.2.3, the "part utility" values are then computed by multiplying the "Weighting factor applic X" column by the corresponding "Evaluation" column. Subsequently, the part utilities of the KPIs within a criterion are aggregated to obtain the utility of that criterion. This process is repeated for all criteria, with their utilities being added together to derive the final score for the AI application X.

The baseline scores of 9,211 for the AGV Fleet Management System and 9,210 for the Inventory Optimization and Demand Forecasting System reflect the high expectations and goals that LogiSmart Solutions has set for these AI applications. They represent the optimal or ideal performance that the company aims to achieve with these applications in terms of improving operational efficiency, reducing downtime, enhancing logistics performance, and minimizing inventory costs.

It's important to note that the baseline scores are not absolute values, but rather serve as reference points for comparison. They can be updated periodically as the organization gathers more data and refines its logistics processes. The establishment of baseline values is just an example of how a company should proceed to set their initial performance expectations and measure the effectiveness of their AI-driven logistics systems. The specific baseline values may vary depending on the organization's goals, objectives, and historical performance records.

Once the baseline scores for each KPI are established, they serve as a benchmark and a reference point against which the actual performance of the applications will be evaluated. During the implementation and operation of the AI-driven logistics systems, the actual performance of the AI applications can be compared to the baseline scores to assess their effectiveness and efficiency. Any improvements or deviations from the baseline scores can be analyzed to evaluate the impact of the AI applications on the logistics operations of the organization.

4.2.5 Implementing the evaluation system

After establishing the baseline scores of the AI applications, the actual and current scores are determined by collecting the necessary information to calculate the KPIs.

This may involve gathering data on KPIs such as delivery times, inventory levels, and orders processed. For instance, the accuracy of automated picking/packing is calculated based on the number of orders accurately processed by automated systems and the total number of orders processed by automated systems. Below is the calculation of the scores for the key KPIs corresponding to each criterion (the same ones whose baseline scores have also been calculated in the previous section), using hypothetical values for our case study. Note that the KPI_{max} and KPI_{min} values for each S_{max} and S_{min} calculation are the same as those previously defined in the $S_{max,baseline}$ and $S_{min,baseline}$ formulas. The calculation of the KPIs and their corresponding remaining scores will not be included here. Instead, the final scores determined in an arbitrary, yet realistic manner will be directly presented in Table 4-9.

$\boldsymbol{Order\ fulfillment\ accuracy}\ (\boldsymbol{Accuracy}) =$

$$= \frac{\#\ of\ orders\ fulfilled\ correctly\ on\ the\ 1st\ attempt\ within\ a\ month}{Total\ \#\ of\ orders\ fulfilled\ within\ a\ month} = \frac{350}{500} = 0{,}7$$

$$\boldsymbol{S_{max}} = \frac{0{,}7 - 0{,}3}{1 - 0{,}3} * 10 = \mathbf{5.714}$$

$\boldsymbol{Order\ processed\ per\ time\ unit}\ (\boldsymbol{Speed}) =$

$$= \frac{\#\ of\ orders\ processed\ and\ shipped\ within\ a\ week}{Total\ \#\ of\ orders\ received\ within\ a\ week} = \frac{100}{150} = 0{,}667$$

$$\boldsymbol{S_{max}} = \frac{0{,}667 - 0}{1 - 0} * 10 = \mathbf{6{,}67}$$

$\boldsymbol{Order\ processing\ capacity}\ (\boldsymbol{Scalability}) =$

$$= \#\ of\ orders\ processed\ within\ a\ day\ = 26\ \frac{orders\ processed}{day}$$

$$\boldsymbol{S_{max}} = \frac{26 - 0}{40 - 0} * 10 = \mathbf{6{,}5}$$

$\boldsymbol{System\ downtime}\ (\boldsymbol{Reliability}) =$

$$= \frac{Total\ downtime\ due\ to\ system\ failures\ within\ a\ month}{Total\ time\ the\ system\ should\ have\ been\ operational\ within\ a\ month} = \frac{25\ h}{720\ h} = 0{,}035$$

$$\boldsymbol{S_{min}} = \frac{0{,}1 - 0{,}035}{0{,}1 - 0} * 10 = \mathbf{6{,}53}$$

$$\boldsymbol{User\ satisfaction}\ (\boldsymbol{User-friendliness})$$

$$= average\ user\ satisfaction\ rating\ obtained\ from\ surveys\ or\ feedback\ mechanisms = 5{,}5$$

$$\boldsymbol{S_{max}} = \frac{5{,}5-0}{10-0} * 10 = \mathbf{5{,}5}$$

$$\boldsymbol{Internal\ transportation\ cost}\ (\boldsymbol{Cost-effectiveness}) =$$

$$= \frac{Total\ internal\ transportation\ cost\ within\ a\ month}{Total\ \#\ of\ units\ (lots)\ delivered\ within\ a\ month} = \frac{28.000\ €}{700\ lots} = 40\ \frac{€}{lot}$$

$$\boldsymbol{S_{min}} = \frac{100-40}{100-7} * 10 = \mathbf{6{,}45}$$

$$\boldsymbol{Compliance\ with\ data\ protection\ and\ privacy\ laws}\ (\boldsymbol{Ethical\ and\ legal\ compliance}) =$$

$$= \frac{\#\ of\ compliance\ violations\ related\ to\ data\ protection\ and\ privacy\ laws\ within\ a\ month}{Total\ \#\ of\ protection\ and\ privacy\ laws} = \frac{3}{100} = 0{,}03$$

$$\boldsymbol{S_{min}} = \frac{0{,}2-0{,}03}{0{,}2-0} * 10 = \mathbf{8{,}5}$$

$$\boldsymbol{Security\ incidents}\ (\boldsymbol{Security}) =$$

$$= \frac{\#\ of\ security\ incidents\ reported\ and\ resolved\ within\ a\ month}{Total\ \#\ of\ security\ incidents\ reported\ within\ a\ month} = \frac{20}{25} = 0{,}8$$

$$\boldsymbol{S_{max}} = \frac{0{,}8-0{,}3}{1-0{,}3} * 10 = \mathbf{7{,}14}$$

$$\boldsymbol{Successful\ integrations}\ (\boldsymbol{Integration}) =$$

$$= \frac{\#\ of\ successful\ integrations\ since\ implemented}{Total\ \#\ of\ attempted\ integrations\ since\ implemeneted} = \frac{12}{20} = 0{,}6$$

$$\boldsymbol{S_{max}} = \frac{0{,}6-0}{1-0} * 10 = \mathbf{6}$$

			AI application 1				AI application 2			
		Relative KPI weight	Relative KPI weight ap-plic. 1	**Weighting factor ap-plic. 1**	**Evalua-tion**	**Part utility**	Relative KPI weight applic. 2	**Weighting factor ap-plic. 2**	**Evalua-tion**	**Part utility**
Accuracy	Order fulfillment accuracy	0,2	0,2	0,069	5,714	0,395	0,2	0,069	5,714	0,395
	Misdeliveries/mis-ships	0,15	0,15	0,052	7,000	0,363	0,15	0,055	7,000	0,383
	Frequency of stockouts/overstocking	0,1	0,1	0,035	6,000	0,207	0,1	0,035	6,000	0,207
	Demand forecasting accuracy	0,15	0,15	0,052	7,000	0,363	0,15	0,052	7,000	0,363
	Order cancellations/returns	0,1	0,1	0,035	6,000	0,207	0,1	0,035	6,000	0,207
	Inventory management precision	0,1	0,1	0,035	6,500	0,224	0,1	0,035	7,000	0,242
	Automated picking/packing accuracy	0,1	0,1	0,035	8,000	0,276	0	0,000	N/A	0,000
	Supply chain delays/disruptions	0,05	0	0,000	N/A	0,000	0,05	0,017	5,500	0,095
	Billing/invoicing accuracy	0,05	0,05	0,017	7,500	0,129	0,05	0,017	7,000	0,121
	Total Accuracy			**0,328**		**2,164**		**0,328**		**2,012**
Speed	Orders processed per time unit	0,2	0,2	0,022	6,670	0,145	0	0,000	N/A	0,000
	Order fulfillment time	0,25	0,25	0,027	6,500	0,177	0	0,000	N/A	0,000
	Order picking/packing time	0,15	0,15	0,016	7,000	0,114	0	0,000	N/A	0,000
	Data processing speed	0,1	0,1	0,011	7,000	0,076	0,1	0,027	7,700	0,210
	Issue/dispute resolution time	0,1	0,1	0,011	5,000	0,055	0,1	0,027	6,500	0,177
	Decision-making speed	0,1	0,1	0,011	6,500	0,071	0,1	0,027	6,500	0,177
	Reaction time to changing market conditions	0,1	0,1	0,011	6,000	0,065	0,1	0,027	8,000	0,218
	Total Speed			**0,109**		**0,704**		**0,109**		**0,782**
Scalability	Order processing capacity	0,25	0,25	0,009	6,500	0,057	0	0,000	N/A	0,000
	Product line capacity	0,2	0,2	0,007	7,000	0,049	0,2	0,009	8,000	0,075
	Fluctuations in demand	0,2	0,2	0,007	6,000	0,042	0,2	0,009	8,000	0,075
	Multi-warehouse capacity	0,2	0,2	0,007	3,000	0,021	0,2	0,009	8,500	0,079
	Carrier diversity	0,15	0,15	0,005	7,000	0,037	0,15	0,007	8,000	0,056
	Total Scalability			**0,035**		**0,206**		**0,035**		**0,285**

Reliability	System uptime	0,2	0,2	0,018	6,530	0,119	0,2	0,018	8,300	0,151
	System downtime	0,2	0,2	0,018	6,530	0,119	0,2	0,018	8,300	0,151
	System failures	0,2	0,2	0,018	7,000	0,127	0,2	0,018	8,000	0,146
	Anomaly detection	0,2	0,2	0,018	7,500	0,137	0,2	0,018	7,500	0,137
	Real-time alerts and notifications	0,1	0,1	0,009	6,500	0,059	0,1	0,009	7,000	0,064
	Continuous improvement	0,1	0,1	0,009	5,500	0,050	0,1	0,009	6,500	0,059
	Total Reliability			**0,091**		**0,611**		**0,091**		**0,707**
User-freindliness	System accessibility	0,1	0,1	0,017	5,500	0,094	0,1	0,017	6,000	0,103
	User satisfaction	0,2	0,2	0,034	5,500	0,188	0,2	0,034	6,000	0,205
	System availability	0,2	0,2	0,034	7,000	0,239	0,2	0,034	8,300	0,284
	Search accuracy	0,15	0,15	0,026	4,000	0,103	0,15	0,026	5,500	0,141
	Personalization	0,1	0,1	0,017	3,000	0,051	0,1	0,017	4,000	0,068
	Documentation and training	0,15	0,15	0,026	7,000	0,180	0,15	0,026	7,000	0,180
	Error messages and feedback mechanisms	0,1	0,1	0,017	6,000	0,103	0,1	0,017	5,500	0,094
	Total User-friendliness			**0,171**		**0,958**		**0,171**		**1,075**
Cost-effectiveness	Internal transportation cost	0,25	0,25	0,020	6,450	0,129	0	0,000	N/A	0,000
	Inventory carrying cost	0,2	0,2	0,016	6,500	0,104	0,2	0,029	6,500	0,187
	Warehouse labor cost	0,2	0,2	0,016	6,000	0,096	0,2	0,029	6,000	0,173
	Contract compliance rate	0,1	0	0,000	N/A	0,000	0	0,000	N/A	0,000
	Order fulfillment time	0,15	0,15	0,012	6,500	0,078	0	0,000	N/A	0,000
	Order fulfillment accuracy	0,05	0,05	0,004	5,714	0,023	0,05	0,007	5,714	0,041
	Asset utilization rate	0,05	0,05	0,004	7,000	0,028	0,05	0,007	7,000	0,050
	Total Cost-effectiveness			**0,072**		**0,458**		**0,072**		**0,452**

Ethical and legal compliance	Discrimination	0,15	0	0,000	N/A	0,000	0	0,000	N/A	0,000
	Ethical or legal violations	0,15	0,15	0,007	8,500	0,060	0,15	0,008	8,300	0,067
	Compliance with transportation safety regulations	0,1	0,1	0,005	8,000	0,037	0	0,000	N/A	0,000
	Compliance with data protection and privacy laws	0,2	0,2	0,009	8,500	0,079	0,2	0,011	8,500	0,092
	Energy consumption and emissions	0,15	0,15	0,007	6,500	0,046	0,15	0,008	6,500	0,053
	Social responsibility impact	0,1	0,1	0,005	6,500	0,030	0	0,000	N/A	0,000
	Algorithms and processes audited for bias and discrimination	0,1	0	0,000	N/A	0,000	0,1	0,005	6,500	0,035
	Frequency of ethical guideline	0,05	0,05	0,002	3,000	0,007	0,05	0,003	3,000	0,008
	Total Ethical and legal compliance			**0,035**		**0,259**		**0,035**		**0,254**
Security	Security incidents	0,3	0,3	0,037	7,140	0,261	0,3	0,037	8,000	0,293
	System downtime due to security incidents	0,2	0,2	0,024	6,500	0,159	0,2	0,024	8,000	0,195
	Response time to security incidents	0,2	0,2	0,024	6,000	0,146	0,2	0,024	8,000	0,195
	Conducted training and awareness	0,2	0,2	0,024	6,000	0,146	0,2	0,024	6,000	0,146
	Stakeholders' security	0,1	0,1	0,012	6,000	0,073	0,1	0,012	6,500	0,079
	Total Security			**0,122**		**0,786**		**0,122**		**0,909**
Integration	Successful integrations	0,35	0,35	0,012	6,000	0,074	0,35	0,012	7,000	0,086
	Resolved integration errors	0,25	0,25	0,009	6,500	0,057	0,25	0,009	7,000	0,061
	Time to complete integrations	0,25	0,25	0,009	4,000	0,035	0,25	0,009	7,000	0,061
	Third-party systems and applications integrated	0,15	0,15	0,005	6,000	0,032	0,15	0,005	6,500	0,034
	Total Integration			**0,035**		**0,197**		**0,035**		**0,242**
	Total AI application utility					**6,342**				**6,717**

Table 4-9: Actual scoring system

In this case, assigning fictitious values to weighting factors, KPIs and scores as an example, overall scores of 6,342 for the AGV Fleet Management System and 6,717 for the Inventory Optimization and Demand Forecasting System have been obtained. These scores are a concrete reflection of the tangible and measurable performance that the company is currently achieving through the utilization of the evaluated AI applications, gauged against the specific criteria that have been carefully chosen to assess their effectiveness. The scores serve as an accurate and factual representation of the actual outcomes and results that the company has attained, providing valuable insights into the real-world impact and efficacy of these AI applications in improving the company's performance.

4.2.6 Analyzing the results

After defining the objectives, evaluation criteria, identifying KPIs for each criterion in the scoring system and filling the baseline and actual scoring system, the next step in analyzing the results is to compare the actual scores obtained from evaluating the fictional logistics enterprise with the baseline scores or previous evaluations that were established earlier. This comparison will provide insights into the performance of the AI applications in internal logistics and help identify any improvements or changes that have occurred since the implementation of the AI applications.

The analysis should be conducted in a systematic and thorough manner. Firstly, the data collected, including the actual and ideal scores for each evaluation criterion and KPI, should be reviewed and compared. This comparison can be done visually using graphical representations such as charts or tables, or through quantitative analysis using statistical techniques. It's important to assess the extent to which the actual scores deviate from the ideal scores and whether these deviations are within acceptable ranges.

A "traffic lights" system can be used as a visual indicator to quickly assess the performance of AI applications in internal logistics based on the scores obtained from the evaluation criteria and KPIs, making it easier to interpret and communicate. This system can use the colors green, yellow, and red to represent different levels of performance, with each color indicating that the performance score falls within a certain range. Green can be used to represent a positive performance. For example, if the actual scores for a particular criterion or KPI are close to or equal to the ideal scores, it can be represented as green, indicating that the AI application is meeting or exceeding expectations in that area. A green light can also be used to indicate that the overall performance of the AI application, considering all the criteria and KPIs, is satisfactory and aligned with the defined objectives. Yellow can be used to represent a cautionary performance. If the actual scores for a criterion or KPI are moderately below the ideal scores, it can be represented as yellow, indicating that there may be some areas that require attention or improvement. Similarly, a yellow light can be used to indicate that the overall performance of the AI application is moderate and may need further evaluation or action to meet the defined objectives. And red can be used to represent a poor performance. If the actual scores for a criterion or KPI are significantly below the ideal scores, it can be represented as red, indicating that the AI application is not meeting expectations in that area and immediate action may be required to address the deficiencies. A red light can also be used to indicate that the overall performance of the AI application is below the desired level and requires urgent attention and corrective measures.

A system of graphics can be used to visually display the development of scores for the criteria and/or the overall performance of the AI application over time, based on periodic evaluations of the AI applications in logistics. Thus, the analysis also considers any potential trends or patterns that may have emerged from the results. For example, line charts can be used to show the trend of scores over time for each criterion or the overall performance of the AI application. Each criterion can be represented by a separate line with different colors or styles, and the scores can be plotted on the y-axis while time is plotted on the x-axis. Line charts allow for easy visualization of how the scores have changed over time, whether they are improving, declining, or remaining stable. One important practice is to always include the baseline scores in the line charts, as they serve as a reference point for visualizing how far or close the AI application is from the desired performance level.

Next, the results should be evaluated in the context of the defined objectives and KPIs. The objectives of the AI applications in internal logistics were established during the initial stages of developing the scoring system, and the evaluation criteria and KPIs were aligned with these objectives. Therefore, the analysis should focus on whether the AI applications have helped to achieve these objectives or not. For example, if the objective was to improve efficiency in warehouse operations, the analysis should assess whether the AI applications have resulted in higher scores in relevant evaluation criteria such as order processing time, inventory accuracy, or resource utilization.

Based on the analysis of the results, appropriate actions can be taken. If the AI applications have met or exceeded the defined objectives and KPIs, it may indicate successful implementation and the need to continue and optimize the use of the AI applications. However, if the results fall short of the expectations, it may require further investigation to identify the root causes and take corrective measures. This could involve refining the AI applications, revisiting the evaluation criteria and KPIs, or making changes to the implementation strategy.

In conclusion, analyzing the results of the scoring system for AI applications in internal logistics involves comparing the actual scores with the baseline/ideal scores or with the scores from previous evaluations, evaluating the results in the context of the defined objectives and KPIs, considering any trends or patterns, and taking appropriate actions based on the findings. This analysis provides insights into the performance of the AI applications and helps in continuously improving their effectiveness in achieving the desired outcomes in internal logistics operations.

4.2.7 Conducting further analysis

Once the initial analysis of the results of the scoring system for AI applications in internal logistics has been completed, it may be necessary to conduct further analysis to gain a deeper understanding of the performance of the AI applications and identify areas for improvement. This can involve several steps:

In addition to the initial analysis, it may be valuable to further analyze the data to identify any patterns or trends that may have emerged over time. This can involve looking at the performance of the AI applications across different evaluation criteria and KPIs, as well as comparing performance over different time periods. For example, if there is a noticeable decline in performance in a particular criterion or KPI over time, further investigation may be needed to identify the reasons behind the decline and take appropriate actions to address it.

If the performance of the AI applications falls short of expectations, it may be necessary to conduct a root cause analysis to identify the underlying reasons. This can involve delving deeper into the data to identify any specific factors or issues that may have contributed to the performance gaps. It may also involve gathering qualitative feedback from stakeholders involved in the implementation and use of the particular AI application to gain insights into any challenges or issues that may not be apparent from the quantitative analysis alone. Root cause analysis can help in identifying the key areas that need improvement and guide the development of targeted solutions.

Evaluation criteria and KPIs may need to be periodically reviewed and refined to ensure they are still relevant and aligned with the objectives of the AI applications in internal logistics. This can involve reassessing the weights assigned to different criteria and KPIs, as well as adding new ones or modifying existing ones based on changing business needs or operational requirements. The review and refinement process should be data-driven and involve input from relevant stakeholders to ensure that the evaluation criteria and KPIs accurately reflect the performance of the AI applications and provide meaningful insights for decision-making.

Qualitative feedback from stakeholders who have been involved in the implementation and use of the AI applications can be useful for gaining a comprehensive understanding of their performance. This can involve conducting surveys, interviews, or focus group discussions with employees, managers, and other relevant stakeholders to gather their perspectives on the effectiveness of the AI applications in internal logistics operations. Stakeholder feedback can provide insights into areas that may need improvement or uncover any challenges or issues that may not be apparent from the quantitative analysis alone.

Benchmarking the performance of the AI applications against industry standards or best practices can provide valuable insights into their relative performance and identify areas that may require improvement. This can involve comparing the performance of the AI applications against industry benchmarks or benchmarks established by other similar organizations or logistics enterprises. Benchmarking can highlight areas where the AI applications are performing well and areas where they may be lagging behind, providing a basis for setting improvement targets and implementing corrective measures.

It's important to consider external factors that may impact the performance of the AI applications in internal logistics operations. This can involve factors such as changes in market conditions, technological advancements, regulatory changes, or shifts in customer demands. Analyzing the impact of these external factors on the performance of the AI applications can provide insights into areas that may require adjustments or improvements to ensure continued effectiveness.

4.2.8 Periodically evaluating AI applications and the impact of changes

Periodical evaluations and impact assessments are imperative in the context of AI applications in internal logistics. These evaluations involve regularly assessing the performance of AI applications with the scoring system to gauge their effectiveness in meeting desired goals and delivering optimal results. As technology evolves and business requirements change, these evaluations allow organizations to compare the current performance of AI applications with past performances, ensuring that they continue to operate at an optimal level.

One of the key reasons why periodical evaluations and impact assessments are important is that technology is constantly evolving. AI applications may require updates or modifications to keep pace with the latest advancements in the field. Periodical evaluations help identify any gaps or shortcomings in the performance of AI applications, allowing organizations to address them promptly and effectively. Also, business requirements and operational contexts can change over time. Periodical evaluations allow organizations to assess whether AI applications are still aligned with the current business requirements and operational goals. If there are any changes in the business environment, such as shifts in customer demand, market dynamics, or operational processes, periodical evaluations help identify any discrepancies and allow for necessary adjustments to be made to the AI applications accordingly to remain effective in supporting the overall business strategy and objectives.

Periodical evaluations and impact assessments also facilitate the comparison of current performance with past performances. By establishing performance benchmarks and tracking performance over time, organizations can measure the progress and effectiveness of AI applications. This information can be used to identify trends, patterns, and areas for improvement. It also helps in identifying potential areas of risk or concern, such as declining performance or deteriorating results, which can be addressed proactively to prevent any negative impact on the business operations.

In addition, whenever changes are made to the AI application, it's important to evaluate their impact on the logistics system. This could involve conducting additional testing and analysis to determine whether the changes have had a positive or negative effect on the system's performance. The purpose of evaluating the impact of changes is to ensure that the modifications made to the AI application have the desired effect on the logistics system. It helps organizations verify whether the changes have resulted in positive outcomes, such as improved performance or enhanced operational efficiency, or if there are any unintended negative consequences that need to be addressed promptly.

In summary, periodic evaluations and impact assessments are essential steps in the ongoing management of AI applications in internal logistics. They help organizations assess the effects of modifications made to the AI applications, maintain alignment with changing business requirements, and support continuous improvement and optimization efforts to ensure optimal performance of the logistics system.

5 Conclusions

According to the purpose of this thesis, the study tries to provide a comprehensive framework for evaluating the performance of AI systems in operational logistics. The study intends to address the growing need for a standardized and objective evaluation system that companies can use to measure the effectiveness of their AI-driven logistics systems. In particular, the research seeks to explore the importance of implementing and evaluating AI technologies in operational and internal logistics fields. The study aims to answer critical questions like how organizations can effectively track, measure, and examine the performance of their AI systems in logistics operations.

With the rapid development of AI and machine learning technologies, there is a growing interest among organizations to deploy AI systems in their logistics operations. However, the lack of a standardized evaluation system for these technologies poses significant challenges for companies seeking to assess the effectiveness of their AI-driven logistics systems. Therefore, the evaluation system proposed in this study is a comprehensive and effective way for companies to evaluate the performance of their AI-driven systems in logistics. One of the primary strengths of this system is that it is designed to be applicable to a wide range of AI applications in the operational logistics area. The general nature of the evaluation system allows companies to tailor it to their specific needs, while still providing a standardized and objective framework for evaluation. Another key strength of this system is the consideration of various criteria and KPIs. By including a diverse range of criteria and KPIs, the evaluation system provides a holistic view of the AI-driven logistics systems' performance, which can help identify areas for improvement. The weighting factor assigned to each KPI allows for the prioritization of different aspects of the logistics operations, depending on the company's objectives and goals. Furthermore, the evaluation system's calculation method for KPI scores, ranging from 0 to 10, is a simple and easy-to-understand approach for companies to measure their AI applications' performance. The multiplication of the KPI score by its weighting factor helps to provide a comprehensive overview of the AI system's performance, allowing for a clear comparison of different AI applications in the logistics field.

Overall, the proposed evaluation system provides a clear and objective way for companies to evaluate the performance of their AI-driven systems in logistics. It serves as a starting point for companies wanting to assess the effectiveness of their logistics operations, providing a standardized evaluation framework while still allowing for customization to meet specific needs. With the inclusion of a diverse range of criteria and

KPIs, and a simple calculation method, this evaluation system is a valuable tool for companies seeking to optimize their logistics operations and enhance overall performance.

As with any research study, there were also certain limitations to this evaluation of AI systems in logistics. One of the limitations was the scarcity of literature available on the topic. While there is a growing interest in the use of AI in logistics operations, there is not much information available yet on how to evaluate the effectiveness of these systems. As a result, this study had to rely on a limited number of articles and sources in the part of the score system, which may have impacted its results. Another limitation of this study was the general nature of the evaluation system. Since the objective was to provide a standardized and objective evaluation framework, the criteria and KPIs had to be as general as possible to be applicable to a wide range of AI-driven logistics systems. However, this may have limited the specificity and the ability to detect areas for improvement in the scoring system once applied to a real case. Additionally, because the evaluation system was designed to be general, there were different ways of analyzing the results from different points of view. While this provided a broad overview of the performance of the AI-driven logistics systems, the analysis of the results from the scoring system could not be as deep and detailed as it would have been in a real case. Therefore, there may have been missed opportunities to identify specific strengths and weaknesses of the evaluated systems.

Overall, while these limitations should be acknowledged, they do not detract from the importance and significance of the proposed evaluation system. The limitations merely suggest areas for future research and improvements that can be made to the evaluation system. In light of these, there are several recommendations for future research in this topic.

The main area of improvement for the evaluation system proposed in this thesis is the implementation of a real case study in a company. By applying the evaluation system to a real company, it will be possible to obtain several scoring results in time and compare them with themselves, the baseline, and benchmark them with industry standards. This would provide a more accurate and precise evaluation of the performance of the AI-driven logistics system. As a consequence, further research could also be applied to develop more specific and detailed evaluation criteria and KPIs for AI-driven logistics systems. This would allow for a more in-depth analysis of the performance of these systems and provide companies with even more actionable insights for improving their operations.

Research could also be conducted to explore the impact of different types of AI technologies on logistics operations. For example, machine learning algorithms and natural language processing systems could be compared to traditional rule-based systems to identify which approach is most effective in different contexts.

Finally, it could be interesting to explore the impact of AI-driven logistics systems not just on the company, but on different stakeholders, such as customers, employees, and suppliers. This could help to identify any unintended consequences of these systems and ensure that they are implemented in a socially responsible manner.

Overall, there are many exciting avenues for future research in the field of AI-driven logistics systems, and it is important to continue exploring these topics in order to unlock the full potential of these technologies.

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Explanation

I hereby certify that I have written the thesis I have submitted independently and have not used any sources or aids other than those specified.

Munich, 28.04.2023

Location, Date, Signature